40037

National Library
of Canada

Bibliothèque nationale
du Canada

**CANADIAN THESES
ON MICROFICHE**

***THÈSES CANADIENNES
SUR MICROFICHE***

NAME OF AUTHOR/*NOM DE L'AUTEUR* MARION JOYCE LINDSAY ALEXANDER

TITLE OF THESIS/*TITRE DE LA THÈSE* A BIOMECHANICAL ANALYSIS OF THE UPPER LIMB SEGMENTS DURING THE SOFTBALL PITCH

UNIVERSITY/*UNIVERSITÉ* UNIVERSITY OF ALBERTA

DEGREE FOR WHICH THESIS WAS PRESENTED/
GRADE POUR LEQUEL CETTE THÈSE FUT PRÉSENTÉE PHD

YEAR THIS DEGREE CONFERRED/*ANNÉE D'OBTENTION DE CE GRADE* 1978

NAME OF SUPERVISOR/*NOM DU DIRECTEUR DE THÈSE* DR. JURIS TERAUDS

Permission is hereby granted to the NATIONAL LIBRARY OF CANADA to microfilm this thesis and to lend or sell copies of the film.

The author reserves other publication rights, and neither the thesis nor extensive extracts from it may be printed or otherwise reproduced without the author's written permission.

L'autorisation est, par la présente, accordée à la BIBLIOTHÈQUE NATIONALE DU CANADA de microfilmer cette thèse et de prêter ou de vendre des exemplaires du film.

L'auteur se réserve les autres droits de publication; ni la thèse ni de longs extraits de celle-ci ne doivent être imprimés ou autrement reproduits sans l'autorisation écrite de l'auteur.

DATED/*DATÉ* Sept 5/78 SIGNED/*SIGNÉ* Marion Alexander

PERMANENT ADDRESS/*RÉSIDENCE FIXÉ*
School of Physical Education
University of Manitoba
Winnipeg, Manitoba

NL-91 (3-74)

National Library of Canada

Cataloguing Branch
Canadian Theses Division

Ottawa, Canada
K1A 0N4

Bibliothèque nationale du Canada

Direction du catalogage
Division des thèses canadiennes

NOTICE

The quality of this microfiche is heavily dependent upon the quality of the original thesis submitted for microfilming. Every effort has been made to ensure the highest quality of reproduction possible.

If pages are missing, contact the university which granted the degree.

Some pages may have indistinct print especially if the original pages were typed with a poor typewriter ribbon or if the university sent us a poor photocopy.

Previously copyrighted materials (journal articles, published tests, etc.) are not filmed.

Reproduction in full or in part of this film is governed by the Canadian Copyright Act, R.S.C. 1970, c. C-30. Please read the authorization forms which accompany this thesis.

THIS DISSERTATION
HAS BEEN MICROFILMED
EXACTLY AS RECEIVED

AVIS

La qualité de cette microfiche dépend grandement de la qualité de la thèse soumise au microfilmage. Nous avons tout fait pour assurer une qualité supérieure de reproduction.

S'il manque des pages, veuillez communiquer avec l'université qui a conféré le grade.

La qualité d'impression de certaines pages peut laisser à désirer, surtout si les pages originales ont été dactylographiées à l'aide d'un ruban usé ou si l'université nous a fait parvenir une photocopie de mauvaise qualité.

Les documents qui font déjà l'objet d'un droit d'auteur (articles de revue, examens publiés, etc.) ne sont pas microfilmés.

La reproduction, même partielle, de ce microfilm est soumise à la Loi canadienne sur le droit d'auteur, SRC 1970, c. C-30. Veuillez prendre connaissance des formules d'autorisation qui accompagnent cette thèse.

LA THÈSE A ÉTÉ
MICROFILMÉE TELLE QUE
NOUS L'AVONS REÇUE

NL-339 (3/77)

THE UNIVERSITY OF ALBERTA

A BIOMECHANICAL ANALYSIS OF THE UPPER LIMB SEGMENTS DURING THE SOFTBALL PITCH

by

©

MARION JOYCE LINDSAY ALEXANDER

A THESIS

SUBMITTED TO THE FACULTY OF GRADUATE STUDIES AND RESEARCH

IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE

OF DOCTOR OF PHILOSOPHY

IN

DEPARTMENT OF PHYSICAL EDUCATION

EDMONTON, ALBERTA

FALL, 1978

THE UNIVERSITY OF ALBERTA

FACULTY OF GRADUATE STUDIES AND RESEARCH

The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies and Research, for acceptance, a thesis entitled ..A BIOMECHANICAL ANALYSIS OF THE UPPER LIMB SEGMENTS DURING THE SOFTBALL PITCH............

submitted by ..MARION JOYCE LINDSAY ALEXANDER................

in partial fulfilment of the requirements for the degree of DOCTOR OF PHILOSOPHY

.....Juris Terauds.....
Supervisor

.....S. W. Mendryk.....

.....E.W. Bedingfield.....

.....J.B. Haddow.....

....
External Examiner
Academy of Physical Education
WROCLAW, POLAND

DATE..JULY 21, 1978..............

ABSTRACT

The purpose of this study was to determine the relative velocities of the three segments of the upper extremity during a highly skilled ballistic movement. The skill chosen for analysis was the windmill pitch in the game of softball.

Four highly skilled softball pitchers, two female and two male, were the subjects in the study. Of the ten pitches performed by each of the subjects during the testing session, the two pitches of each subject with the highest velocity were chosen for detailed analysis. The subjects were filmed by two cameras, one placed to the side at right angles to the direction of the pitch, and the other one placed to the rear of the subject. The subjects also pitched from a force platform, so that the reaction of the pitcher on the ground could be recorded. The records from the two cameras and the force platform were synchronized by means of an electric timer, such that the speed of the timing flashes was altered at a point in the pitch.

Other problems investigated in this study included the determination of the coordinates of the segmental endpoints of the pitching arm in three-space, and the comparison of these with the values obtained from the planar analysis. Also, a method was devised to calculate the magnitudes of the angular velocities of the lower arm segment which could be utilized to determine these parameters for any of the other body segments. In particular, the angular velocities

of particular interest were those occurring around the longitudinal axis of the segment, which were believed to be of importance in this skill.

Computer programs were written to calculate the kinematic and kinetic parameters of the segments of the upper extremity during this skill from the digitized film data. The spatial coordinates of the segmental endpoints were determined by use of an available computer program, and the X,Y, and Z velocity components of each of these points were determined and graphed. The pitching arm was analyzed further during the frames surrounding release of the ball to determine the magnitudes of the angular velocities around the three principal axes of the lower arm segment.

The following are the main results of the study: (1) the force platform and the calculated forces from the mass center accelerations produce similar X and Y force records, (2) there is a definite sequence of segment motions which characterizes the highly skilled performers analyzed in this activity, (3) the largest, most proximal arm segment reaches maximum velocity at the earliest point in the skill, followed by the peak velocities of the distal segments, (4) the proximal segment also attains peak acceleration earliest in the skill, followed by the peak accelerations of the other two segments, (5) the directions of the force and acceleration vectors are almost 90 degrees different from those of the velocity and displacement vectors for these segments (6) the most forceful muscle action occurring in this skill is that produced by the shoulder extensors in decelerating this segment prior to release of the ball (7) the three dimensional coordinates produced from the film in this study are fairly accurate (+ or - 7%) estimates of these points, (8) the Z-component of the velocity of the arm segmental endpoints is relatively small (approximately twenty per cent of the X and Y values), and probably relatively unimportant in this skill (9) the peak value for the angular velocity of the pronation movement of this skill occurs at the same instant as the peak velocity for the elbow flexion movement.

ACKNOWLEDGEMENTS

The author wishes to thank:

DR. J. TERAUDS, her chairman, for encouragment and assistance throughout the entire study;

DR. J. HADDOW, for patience and assistance in analysis methods;

I would like to extend my sincere appreciation to my other committee members;

DR. T. BOBER, external examiner;

DR. E.W. BEDINGFIELD, DR. S. MENDRYK, and DR. A. QUINNEY, for their assistance and suggestions.

A special thanks is extended to my subjects for this study: MR. DALE SMITH, MS. BERNICE LECHNER, MS. SUE WILCOX, and MR. CLINT MARSHALL.

TABLE OF CONTENTS

CHAPTER PAGE

I THE PROBLEM 1

Introduction 1
The Problem 9
Statement of the Problem 13
Subproblems 14
Delimitations 14

II RELATED LITERATURE 16

General Segmental Analysis Techniques 16
Analyses of Ballistic Skills 34
Upper Extremity Analyses 38
Data Smoothing Techniques 46
Analyses of Softball Pitching 51
Three Dimensional Cinematographic Techniques 53
Force Platform Studies 62

III PROCEDURES 65

Experimental Procedures 65
   Pilot Study 65
Testing Apparatus 68
   Filming Equipment 68
   Force Plate 69
   Film Analysis Equipment 70
   Subjects 71
   Subject Preparation and Measures 72
   Filming Procedures 73
   Force Plate Procedures 76
Analysis of Data 77
   Subject Pitching Data 77
   Pitching Parameters 79
   Body Segment Parameters 80
   Ground Reaction Forces 86
   Angular Kinematics 88
   Linear Kinematics 90
   Single Plane Kinetics 91
   Three Dimensional Analysis 93
   Three Dimensional Angular Velocities 96

TABLE OF CONTENTS continued

IV RESULTS AND DISCUSSION 99

Introduction to Analysis of Results 99
Individual Subject Data 100
Description of the Pitching Motion 103
Ball Velocities 118
Ground Reaction Forces 120
Angular Kinematics 124
  Angular Displacements 124
  Angular Velocities 168
  Angular Accelerations 172
Linear Kinematics 174
  Linear Velocities 174
  Linear Accelerations 177
Linear and Angular Kinetics 179
  Resultant Forces at the Joints 179
  Resultant Moments at the Joints 181
Three Dimensional Analysis 184
Three Dimensional Angular Velocities 197

V SUMMARY AND CONCLUSIONS 202
Summary 202
Conclusions 203
Recommendations 207

BIBLIOGRAPHY 208

APPENDIX A Filming Data 219

APPENDIX B Three Dimensional Program Description 221

APPENDIX C Equations for Planar Analysis 228

APPENDIX D Equations for Three Dimensional Analysis 237

APPENDIX E Computer Program for Segmental Analysis 243

APPENDIX F Computer Program for Angular Velocities 252

APPENDIX G Raw Data for Planar Analysis 257

APPENDIX H Raw Data for Three Dimensional Analysis 328

LIST OF TABLES

Table	Description	Page
I	Subject Data for Kinetic Analysis	85
II	Individual Subject Data	101
III	Stride Length and Temporal Characteristics	104
IV	Ball Velocities of Pitched Balls	115

LIST OF FIGURES

Figure Page

1. Sequence Photographs of Subject 1 108
2. Sequence Photographs of Subject 2 109
3. Pitching Motion of Subject 1 113
4. Pitching Motion of Subject 2 114
5. Path of Segmental Endpoints of Subject 1 116
6. Path of Segmental Endpoints of Subject 2 117
7. Ground Reaction Forces of Subject 1 121
8. Ground Reaction Forces of Subject 2 122
9. Angular Position vs Time of the Arm Segments for Subject 1 125
10. Angular Velocity vs Time of the Arm Segments for Subject 1 126
11. Angular Acceleration vs Time of the Arm segments for Subject 1 127
12. X and Y Linear Velocities of the Segmental Endpoints for Subject 1 128
13. X and Y Linear Accelerations of the Segmental Endpoints for Subject 1 129
14. X and Y Joint Forces for Subject 1 130
15. Resultant Moments at the Joints for Subject 1 131
16. Angular Position vs Time of the Arm Segments for Subject 1 132
17. Angular Velocity vs Time of the Arm Segments for Subject 1 133
18. Angular Acceleration vs Time of the Arm segments for Subject 1 134

LIST OF FIGURES continued

19. X and Y Linear Velocities of the Segmental Endpoints for Subject 1 135

20. X and Y Linear Accelerations of the Segmental Endpoints for Subject 1 136

21. X and Y Joint Forces for Subject 1 137

22. Resultant Moments at the Joints for Subject 1 138

23. Angular Position vs Time of the Arm Segments for Subject 2 139

24. Angular Velocity vs Time of the Arm Segments for Subject 2 140

25. Angular Acceleration vs Time of the Arm segments for Subject 2 141

26. X and Y Linear Velocities of the Segmental Endpoints for Subject 2 142

27. X and Y Linear Accelerations of the Segmental Endpoints for Subject 2 143

28. X and Y Joint Forces for Subject 2 144

29. Resultant Moments at the Joints for Subject 2 145

30. Angular Position vs Time of the Arm Segments for Subject 3 146

31. Angular Velocity vs Time of the Arm Segments for Subject 3 147

32. Angular Acceleration vs Time of the Arm segments for Subject 3 148

33. X and Y Linear Velocities of the Segmental Endpoints for Subject 3 149

34. X and Y Linear Accelerations of the Segmental Endpoints for Subject 3 150

35. X and Y Joint Forces for Subject 3 151

36. Resultant Moments at the Joints for Subject 3 152

LIST OF FIGURES continued

37. Angular Position vs Time of the Arm Segments for Subject 4 153

38. Angular Velocity vs Time of the Arm Segments for Subject 4 154

39. Angular Acceleration vs Time of the Arm segments for Subject 4 155

40. X and Y Linear Velocities of the Segmental Endpoints for Subject 4 156

41. X and Y Linear Accelerations of the Segmental Endpoints for Subject 4 157

42. X and Y Joint Forces for Subject 4 158

43. Resultant Moments at the Joints for Subject 4 159

44. Resultant Moments at the Joints for Subject 2 160

45. Resultant Moments at the Joints for Subject 3 161

46. Hand and Wrist Linear Velocities for Subject 1 162

47. Hand and Wrist Linear Velocities for Subject 2 163

48. Elbow and Shoulder Linear Velocities for Subject 1 .164

49. Elbow and Shoulder Linear Velocities for Subject 2 .165

50. X,Y,Z Linear Velocities of Hand for Subject 1 186

51. X,Y,Z Linear Velocities of Hand for Subject 2 187

52. X,Y,Z Linear Velocities of Wrist for Subject 1 188

53. X,Y,Z Linear Velocities of Wrist for Subject 2 189

54. X,Y,Z Linear Velocities of Elbow for Subject 1 190

55. X,Y,Z Linear Velocities of Elbow for Subject 2 191

56. X,Y,Z Linear Velocities of Shoulder for Subject 1 ..192

57. X,Y,Z Linear Velocities of Shoulder for Subject 2 ..193

58. X,Y,Z Linear Velocities of Ball for Subject 1 194

LIST OF FIGURES continued

59. X,Y,Z Linear Velocities of Ball for Subject 2 195

60. W1,W2,W3 Angular Velocities for Subject 1 198

61. W1,W2,W3 Angular Velocities for Subject 2 199

62. Position of the Cameras in Space 227

63. Free Body Diagram of the Softball Pitch 230

64. Reference Frames of Arm Segments 242

65. Points on Lower Arm Segment 242

CHAPTER I

THE PROBLEM

Introduction

"I often say that when you can measure what you are speaking about and express it in numbers you know something about it; but when you cannot measure it, when you cannot express it in numbers, your knowledge is of a meagre and unsatisfactory kind"(Kelvin, 1891, quoted by Panjabi and White,1971:203).

The science of biomechanics is a relatively new science compared with the other disciplines of physical education. As Nelson(1973:336) has stated: "Within the field of sport and physical education, however, biomechanics has progressed slowly and today remains relatively underdeveloped. This lack of development is characterized by a limited number of qualified researchers, a shortage of well equipped, productive laboratories, a small number of graduate programs training doctoral students and a general lack of identity in the scientific community." The first biomechanics conference of note in North America was held at Indiana University in 1970 (Cooper,1971), and the First International Conference was held in 1967 (Wartenweiler,1968). As Nelson further noted (1973:337): "The 1st International Seminar on

Biomechanics held in Zurich, Switzerland, in 1967 was a milestone for the emerging discipline of sport biomechanics." Because the science is itself so new, it is only comparatively recently that biomechanics researchers have had the technological tools to acquire large amounts of accurate data with which to describe human body motion. Some of the most useful tools used in biomechanics research include precision high speed 16 mm movie cameras,electromyography recorders, force platforms, electrogoniometers, and sophisticated multi-channel recording devices to record and integrate data from these sources. Some of the most dramatic advances have been made in film analysis procedures. Where at one time all film data digitizing and reduction was done by hand, much of this work is now automatized. By using a digitizing board attached to a digital computer, it is now possible to analyze large amounts of film data in a relatively short period of time.

Many of the recent studies in biomechanics use the mathematical methods of engineering mechanics to describe and calculate the kinetic and kinematic parameters of a performance from digitized film data (Miller,1970; Dillman,1970; Jensen,1972). Many of the earlier studies concerned with skill analysis used a qualitative approach, in which the major movements of the skill were described qualitatively rather than quantitatively. Those researchers who used a quantitative approach often concluded that the joint or segment with the largest final velocity was the greatest contributor to skilled performance in the activity. A series of recent studies from the university of Iowa (Hay et al., 1975a, 1975b, 1977) have determined that this is not often the case. In fact, the joint or segment with the highest velocity may have received this velocity from a preceding movement. In this case, this joint is only a transmitter of some previously-produced velocity, and the movement of this joint should not accurately be described as the "major contributor" to performance, as it was by Cooper (1972:124). In order to determine the relative contribution of each of the body segments to a skill, it is necessary to use a segmental analysis approach, whereby the kinematic and kinetic characteristics of each of the segments are determined (Plagenhoef, 1971).

Another area of biomechanics research which has recently been explored by means of the segmental analysis method of engineering is that of muscle analysis, that is determination of the muscle action which is occurring during a particular joint movement. Plagenhoef (1971:55) has described body motions in which muscle action at one joint can produce muscle action at an adjoining joint just opposite to what the movement indicates. An example of this is seen in the standing broad jump where hip extension is so great that the knee flexors are dominant even though ~~the~~ legs are straightening. This is due to the fact that the motion of a segment affects both ends of the segment, so that when the hips are forcefully extending the thigh segment is moved in that direction. Since the knee joint is at the other end of the segment, it also moves in the direction of the hip extension, which may also be the direction of knee flexion. Although the movement at the knees is extension, the moment at the end of the thigh segment may be one towards flexion. A further example of the misconceptions in muscle analysis which are common in the analysis of skills is described by Gideon Ariel in an article by Moore(1977). In a study of major league pitchers, Ariel found that the forearm flexor muscles which act to flex the wrist have practically no contribution to make to this skill. The force of the pitch is built up by the legs and trunk rotation, and the hand is like the end of a whip. The wrist movement is far faster than any muscle can contract, so it is not really useful to attempt strength training of the wrist, according to Ariel. This could only be determined conclusively by comparing accurate estimates of muscle contraction times for the wrist flexor muscles with the actual linear velocities of the insertions of these muscles in the hand. A study of this type would of course be limited by the anatomical and physiological data available.

Another common problem in skill analysis has been the difficulty of accurately describing the movements which contribute to skilled performance. Since most of the previous research has been single-camera, two-plane research,only movements occurring in this plane(most commonly the sagittal plane) have been described. A common example of errors in this area is seen in the usual descriptions of wrist movements in racquet sports. In badminton, for example, this movement has traditionally been referred to as "wrist snap", or the "uncocking of the wrist". recent investigations by Waddell and Gowitzke(1977) have determined that the primary force-producing movement in the badminton overhead smash is rotation of the forearm (pronation) accompanied by shoulder rotation,not the movements of flexion and extension that are usually described in this context. The final force-producing movement which provides so much of the force is not likely the wrist flexion movement described by such authors as Cooper and Glassow(1973)---this wrist flexion is probably quite minimal. The most important movement in this skill is likely the forceful forearm pronation just prior to release of the ball, as found by Waddell and Gowitzke(1977) in the badminton overhead clear. It is notable that even though the majority of textbooks describe the pitch incorrectly, most highly skilled performers manage to execute it correctly regardless of these descriptions. As noted by Harrs(1978:84): " ---players who have been taught to play overhead strokes according to the prevailing literature, manage to do so in spite of what they are being taught".

A further source of error in skill analysis is seen in calculation of acceleration at the joints. When calculating these accelerations, both the tangential and the normal components of the acceleration must be calculated. The resultant of these often produce unpredictable force directions. As Plagenhoef(1966:111) has noted: "A slow moving but greatly accelerating segment can have a force direction almost 90 degrees different than if the segment were moving at a uniform velocity." It is clear that the intricate patterns of movement of the skilled performer cannot be described accurately without detailed analysis of each segment and its effects on the adjoining segments.

There has been much written in the literature of movement analysis and kinesiology regarding the pattern of limb movements during ballistic sports activities (Rasche and Burke,1974; Wells and Luttgens,1976; Broer,1973; Cooper and Glassow,1972). Ballistic sports activities include those skills characterized by high-velocity limb movements. Wells and Luttgens(1976) have described a ballistic movement as one which is initiated by vigorous muscular contraction and completed by momentum. These movements are characteristic of throwing, striking, and kicking, and are found in virtually all the sports and activities which physical educators are responsible for teaching.

The movement chosen as a representative ballistic skill in the present investigation was the windmill pitch in the game of softball, since it has the required characteristics of a multi-segment movement of relatively high velocity. Much of the literature is in disagreement as to the general pattern of segment motion during high velocity limb movement. Several authors (Broer,1973; Cooper and

Glassow,1972) described this limb movement in terms of "successively added segmental velocities", while others (Rasche and Burke,1974; Wells and Luttgens,1976) described it as "sequential joint movement, from proximal to distal segments." The movement sequence has also been described as a sequence in which the joints begin their acceleration when the preceding joint has reached its maximum acceleration, so that the end of the lever is constantly being accelerated by successive segments (Bunn, 1972). Recently, however, several authors have contradicted these earlier descriptions of this movement pattern, and have suggested that optimal velocity at the distal end of a lever is produced by a 'slowing down' of the proximal segments. It is clear that more study is needed to determine the exact sequence of segment movements in a common ballistic skill.

The skill of windmill pitching in softball was chosen for analysis for several reasons, one of the most important of which is the universal and increasing popularity of the sport in Canada. It has been estimated that there are more Canadians of all ages and social classes playing softball than any other single sport. A popular magazine has recently reported that: "Softball is the game that everyone plays and hardly anyone watches, the game that is to baseball what checkers is to chess. And it is my guess that more Canadians have played softball than have skated, curled or jogged" (O'Malley,1977:65). As well, softball is a sport in which Canadian teams are among the top in the world. The Men's

World Champions for the past several years have been Canadian teams (O'Malley,1977) and the Canadian Women's Champions have ranked among the top four in the world for the past five years.

Several authors have stated that the softball pitcher is the most important player on the team, and that the skill of the pitcher may account for up to seventy five per cent of the success of a team (Dobson and Sisley, 1971; Kneer and McCord, 1976). With the current popularity of this game, and the importance of the skills of the pitcher to a team's success, it is clear that a closer examination of this skill would be valuable to a large number of participants. Further, the skill of softball pitching has always been fascinating to both players and spectators alike, as noted by O'Malley(1977): "It is this aspect of softball (pitching) which fascinates me, how anyone can throw a ball that big that fast with an underhand motion one might use to plop wet tea bags into the sink. It looks incredible, like a man jumping 20 feet into the air.---the underhand throw is natural and the overhand baseball throw is an aberration (O'Malley,1977:65)". It is hoped that the present study will give greater insight into the factors which comprise a skilled performance in softball pitching, as a high velocity ballistic movement.

The Problem

The purpose of this investigation was to examine the motions of the three segments of the arm during the delivery of the ball in the softball pitch, and thereby describe the relative motions of each of the segments during a skill of this type. There are some questions among kinesiologists and biomechanics researchers regarding the three segments which are contributing to the velocity of the ball during the softball pitch. Are they accelerating, decelerating, or maintaining a constant velocity through release? These questions extend to the angular motions of the limbs as well, whether their angular accelerations are increasing, decreasing, or constant. Since the objective of the softball pitch is to release the ball at the optimal velocity of the hand (in most cases), loss of velocity of the proximal segments would be inefficient. It seems logical that the upper arm segment and the lower arm segment should maintain their maximal velocity through the release of the ball. This should ensure maximum release speed. However, several authors have recently suggested that it is desirable to have the proximal segments slow down prior to release during a throw.

Plagenhoef(1971:55) described the extent of the contribution of each body segment as follows: "The movement of the segment nearest the fixed point should accelerate and increase velocity; then the deceleration of that first segment aids the increase in velocity of the next segment. The same sequence takes place so that the deceleration of segment 2 aids the increase in velocity of segment 3. The timed sequence of one segment helping the next will produce the maximum velocity of the last segment with a minimum of muscle force at each joint." Broer (1973:87) continued with this theory when she noted: "This deceleration of the preceding segment acts to stabilize the axis for the motion of the second segment. In sequential action the first segment rotates around its axis, the second rotates around the moving end of the first segment, and the third around the moving end of the second. Thus, to gain maximum rotation of the second around its axis (the end of the first), the first segment must decelerate." Gideon Ariel, quoted by Moore (1977) in a recent popular magazine article, agreed with the previous authors when he stated: "It's vital to have everything stopping in the discus. In the best throws, we found a pattern. It is like using a fly rod, or snapping a towel. You have to decelerate the heavy parts, the legs and the trunk, so you can accelerate the light parts, the arm and the discus." This principle of deceleration of preceding body parts was summarized by Plagenhoef (1966) as follows: "The velocity of a given segment can be increased by decelerating the adjoining segment. (In whole body motions where a peak velocity is desired in the hands, the properly timed stopping action of each segment from foot to hand produces the best results)". It is clear that this question of relative segment motions requires further investigation, as no accurate data describing the relative motions of the arm segments in a throwing motion is presently available.

The method most commonly used in current biomechanics research to examine questions of this type is known as segmental analysis. Each segment of the body is viewed as a link of variable length and weight for each subject, and segment movements can be described as motion about axes created by the joints (Jensen,1972). The motions of segments may be described in terms of the displacements, velocities, and accelerations of their endpoints and of their respective centers of gravity, as well as by the angular equivalents to these. As well, from these kinematic parameters the magnitudes of the forces acting on these segments and at the joints may be estimated.

A further problem to be investigated in this study was the relative contributions of rotational movements of the segments around their own longitudinal axes to ball velocity. Little research has been located which examined the rotational movements of the body segments due to the dificulties in accurately measuring these from two-dimensional data. However, it is possible to measure accurately these rotations around the longitudinal axis of the segment by means of two camera filming procedures, whereby the data from these two cameras can be coordinated to produce three dimensional coordinates of any of the points on these segments. No previous attempts to actually quantify the amount of shoulder medial rotation and forearm pronation present during the softball delivery were located. It is likely, however, that these movements are major contributors to the force in this skill.

Another question which was investigated in this study is the accuracy of the calculated ground reaction forces from film coordinate data, compared to force platform readings. The vertical and horizontal components of the acceleration of the body's center of gravity provides estimates of the forces being exerted down and back against the ground during the performance of a skill. Assuming that the force platform readings of these same forces are accurate, these readings may serve as checks on the accuracy of the calculations from film data.

A final question which was examined within the framework of the present study was the relationship between the two dimensional data produced from one camera placed at right angles to the direction of the movement, and the data produced from three-dimensional coordinates of the same data. This may give some insight into the actual amount of error present in the traditional one-camera, two dimensional analysis of physical skills. For example, in the calculation of the velocity of the hand during the release of the ball, a one camera view does not take into account any movements of the hand in the plane at right angles to the lens of the camera. It is possible that these lateral and rotational movements at the joints are important contributors to the final velocity of the ball. A two camera view of the same skill, however, gives a more accurate estimate of the position of the hand in space, and so any movements which occur out of the sagittal plane are considered in the determination of the real velocity of the hand. It is hoped that the present study will also provide a comparison of the relative accuracy of two dimensional analysis of an activity which is actually occurring in three planes.

Statement of the Problem

The purpose of this study was to examine the motions of the three segments of the arm during the delivery of the ball in the softball pitch. In particular, the following objectives were set:

1. To examine the relative motions of the upper limb segments during the execution of the softball windmill pitch.
2. To examine the forces acting at each of the three joints of the upper limb during the windmill softball pitch.
3. To determine the direction of the moments acting at each of the joints during the pitch.
4. To determine the body movements which are most

significant in contributing to the velocity of the ball at release.

5. To estimate the muscle actions during the pitch.

Subproblems

1. To examine the relationship between the forces as measured by the force plate tracings, and the same forces as measured from film data.

2. To examine the relationship between certain kinematic parameters as calculated from two-dimensional film data, and the same parameters as measured from three-dimensional coordinates.

3. To examine the rotational motions of the three segments of the upper limb.

4. To develop a technique for the production of accurate three-dimensional coordinates from film data, and to analyze these coordinates in a meaningful manner.

Delimitations

1. The analysis of the upper limb segment motions of a ballistic movement was limited to the single skill of softball pitching.

2. The analysis was limited to the pitching motions of four highly skilled softball pitchers.

CHAPTER II

RELATED LITERATURE

The literature related to this study was classified into seven topical areas:

1. General Segmental Analysis Techniques
2. Analyses of Ballistic Skills
3. Upper Extremity Analyses
4. Data Smoothing Techniques
5. Analyses of Softball Pitching.
6. Three Dimensional Cinematographic Techniques.
7. Force Platform Studies.

General Segmental Analysis Techniques

Many of the earlier researchers in physical education analyzed sports' skills on a qualitative basis--they simply described what the performance looked like to a trained observer. This method obviously lacks accuracy, as the results are dependent upon the observational powers of the researcher. Recent investigators have used the segmental method of analysis of human movement, in which each of the body segments is considered as a separate body for the purposes of analysis (Dillman,1971; Miller and Nelson, 1973). This method is derived from the methods of engineering analysis, whereby all the forces acting must be quantified and included in the analysis.

Most of the human body mathematical and segmental analysis techniques were derived from the United States space research program (Kane, et al., 1972; Kane and Scher, 1970; Dempster, 1955). One of the most often quoted studies from this program is that produced by Hanavan(1964), which has been used extensively by subsequent researchers in sports' biomechanics (Miller, 1970; Plagenhoef, 1971). Hanavan produced a mathematical model for predicting the inertial properties of a human body in various positions. He used twenty-five standard anthropometric dimensions to predict an individual's center of gravity, the moments of inertia and products of inertia about axes through the center of mass, principal moments of inertia about the principal axes through the center of mass, and the orientation of the principal axes. One of the reasons for the study was to make more efficient use of a propulsion device known as a Self Maneuvering Unit, which was designed for use outside a space vehicle. Undesirable rotations were produced when the thrust vector did not pass through the center of mass of the system, or the torque was produced about an axis other than a principle axis. It was therefore vital to determine the exact positions of the center of mass and the principle axes of the human body, since to that time no such studies had been attempted. Hanavan concluded that his model was capable of predicting these parameters accurately enough to be useable in subsequent space program research.

A later attempt at mathematical modelling of the human body was produced by Huston and Passerello(1971), who developed a set of governing equations to describe human body motion which were applicable to a wide variety of situations. They noted that a principal source of difficulty in developing these equations was the complex geometry due to the irregular shape of the body and its' wide range of possible motions. They used the segment models as described by Hanavan (1964), and they described a series of reference frames to locate the positions of each of the segments within the model. They used a number of configuration charts to enable them to express unit vectors of one reference frame in terms of unit vectors of another reference frame; and another technique known as 'shifters' to relate the scalar components of vectors between different reference frames. They then developed a set of kinematical equations to describe the motions of each of the segments. Three sample motions were studied to illustrate the use of these equations: a lifting motion in two different gravitational fields (earth and moon), a kicking motion in swimming, and a kicking motion by a vertically suspended man. In most cases the input and output curves of the motion were similar, indicating that the mathematical modelling was fairly accurate for these particular movements.

The most popular method of acquiring human motion data used by sports' biomechanics researchers is by cinematography--usually by use of high speed 16mm motion pictures. As well as mathematical modelling from anthropometric measures, biomechanics researchers have devised numerous methods of measuring and quantifying human movement parameters. Researchers in other fields have used several other methods of data gathering, some of which have been described by Ayoub(1972). He has described the use of accelerometers to calculate the forces being exerted during movement, as well as the use of potentiometers at the joints to record the range and velocity of movement. The signals from these devices can be recorded on a strip chart recorder. Padgaonkar(1975) also described a technique of kinematic analysis using accelerometers to measure linear accelerations, and then computation of angular accelerations from this data. He stated that although it theoretically requires a mimimum of six linear accelerometers to determine the kinematics of a rigid body in three dimensions, attempts using only six were unsuccessful in accurately determining these kinematic parameters. An alternate method of determining angular accelerations was suggested based on the placement of nine accelerometers on the segment. He noted that the key to the accurate solution to the problem of accurately describing the motions is the choice cf location of the accelerometers. If the solutions are then accurate, the resulting acceleration values may then be integreted to produce estimates of the angular velocity and displacement. This method may only prove useful for motions involving low values of linear and angular acceleration data.

Ramsey(1968) developed a device which mounted externally on the human subject for the purpose of measuring the kinematic characteristics of his limbs.

Another study which utilized accelerometers to measure the accelerations of a segment was that of Cavanagh and Landa(1976) in an examination of the karate chop. They utilized the methods of cinematography, accelerometry, and electromyography to study the preimpact movements of the arm during karate chops intended to break several boards. Their kinematic analysis showed a sequential pattern of action at the shoulder and elbow joints, with shoulder action nearly complete before the elbow extension began. The linear acceleration of the forearm at the wrist was measured by an accelerometer mounted over the radial styloid. This component of radial acceleration was found to be a maximum of 7 g as recorded by direct measurement from the accelerometer. As well, "a second estimate of acceleration was calculated from numerical double differentiation and this showed considerable variation from the accelerometer measurement (1976:610)". The authors published graphical comparisons of the acceleration data derived from these two experimental sources, and they concluded that "The discrepancies both in amplitude and in phase are considerable, casting further doubt on the process of double differentiation (1976:615)". This 'Exoskeletal Kinematometer' was developed for measuring angular displacements of the joints of the upper limbs by the use of potentiometers at these joints which are sensitive to changes in joint angles. The displacement data from the Kinematometer provided the information necessary for the calculation of instantaneous velocity, acceleration, potential and kinetic energy, force, torque, linear impulse, and angular impulse. He determined that angular impulse was the best single measure of human effort and could provide the most reliable quantification of this effort.

Zernicke(1977) has described the techniques of segmental analysis as they may be applied to analysis of cinematographic data, although his study was concerned with the analysis of a particular weight lifting skill. The sequence of film images was projected onto a digitizer, and rectangular coordinates were digitized for each of the segmental endpoints as well as the center of gravity of the weight. These coordinates were analyzed by computer programs which included the calculation of center of gravity locations and segmental inclinations for each time interval between frames. Following this, "Film-derived kinematic segmental linear and angular accelerations and mass parameter estimates were incorporated into the kinetic equations of motion for a mathematical model of the lifter" (Zernicke,1977:179). The net forces and moments of force at each joint were calculated from the equations of Newtonian rigid-body dynamics. Each of the segments was considered to be a rigid body, and for each segment the sum of the horizontal and vertical forces was equal to the product of the segment mass and the corresponding horizontal and vertical acceleration of that segment's center of mass. Also, the sum of the moments of force was equal to the product of the segment's angular acceleration and the appropriate moment of inertia about the segment's center of gravity. This computational model was validated by comparing the computed vertical reaction forces at the foot, with those measured from a force platform. The mean agreement between the two techniques was found to be greater than 93.0 per cent.

Sutherland and Hagy(1972) conducted a study of the leg movements during gait, as recorded on movie film. One of the problems they discussed was that of estimating the amount of medial and lateral rotation occurring in the leg segments and the pelvis during locomotion. By calculating the angle between measurements of a certain distance taken from the film from the front camera, and the angle between the same distance taken from the side camera, the investigators had developed an accurate estimate of these rotations. These techniques are especially useful when examining the differences between normal and pathological gait, and may be used in analysis of the rotations in any of the body segments. It may then be possible to adapt this technique to estimate the rotations of the arm segments during a throwing motion.

One of the earliest physical education researchers to advocate the use of segmental analysis in examining sports skills was Plagenhoef(1966). In this early article he described the steps necessary to follow in using this technique to accurately quantify film data. These steps included: determining the length and weight of each body segment, filming the motion, tracing the entire motion, locating the center of gravity and radius of gyration for each segment, and calculating the required parameters. Plagenhoef (1971) described these techniques in greater detail in a subsequent book. In this publication, he outlined the procedures for segmental analysis with much more explanation, and as well he included the equations of motion for each of the segments in a multi-segment model. His analysis differed from that used by other investigators in that he included a term for the Coriolis acceleration in his equations--this term has traditionally been neglected by most sports' researchers.

The Coriolis effect is simply the tendency of an object to drift sideways during movement on the earth--to the right in the northern hemisphere, and to the left in the southern hemisphere. This motion is due to the counterclockwise spinning of the earth around it's longitudinal axis, so that objects moving across the surface of the earth tend to move slightly with respect to their original path. As noted by McDonald(1952) in an article on the subject: "This tendency to drift sideways--is due simply to the rotation of the earth, and it appears in all motions as soon as we refer those motions to any coordinate system fixed with respect to the earth (eg., the latitude-longitude grid)". He is of the opinion that the effects of this force should be included in the examination of movements, as he noted: "All things that move over the surface of our spinning earth, whether birds, winds,----bullets, or rockets are inevitably subjected to this effect as we view them in our terrestrial coordinate systems. Even when man gets away from his planetary home and stakes out better behaved coordinate systems in interplanetary space, he will not be able to omit consideration of the Coriolis effect from his dynamics. (McDonald, 1952:77)". However, contrary to this opinion, it is common practice in the study of the motion of body segments to neglect the velocity and acceleration components due to Coriolis motion between moving links (Ayoub, et al., 1976; Pearson, et.al ., 1963).

The techniques of segmental analysis have been extensively revised and reviewed by Plagenhoef (1966, 1968, 1971, 1973), from his early models encompassing one or two segments he developed models including a large number of segments of the whole body. He has recently described a technique to obtain the joint forces due to motion at all segmental endpoints of the body (Plagenhoef, 1973). Separate frames of whole-body motion as recorded by cinematography were analyzed. A system of body links was chosen which would best define the desired forces and this set of segments was known as the primary chain. The forces due to body segments outside of the primary chain were introduced as external forces at appropriate points.

The procedure was then to solve the smaller systems of links for certain unknowns which were necessary to solve the links of the primary chain. These forces and moments determined from earlier analyses were applied at the appropriate points--from here the final link system can then be analyzed.

This technique was used in a study by Stapleton and Karas(1968) in which the skill of swinging on the parallel bars was analyzed. A free body diagram was constructed of the forces acting on the various joints during this action, and especially the forces acting on the shoulder joint. The moment of force due to the acceleration of the shoulder joint during the upward swing phase of this skill was found to be considerable. An attempt was also made to calculate the moments of inertia of the trunk and legs from the data calculated in this study.

Segmental analysis techniques were also utilized by Susanka(1974) to develop computer programs to analyze sports' movements. His programs were similar to those described earlier by Plagenhoef, in that both accepted as input film data points, and the output from the program consisted of displacements, velocity, and acceleration as a function of time. In addition, horizontal and vertical components of force and their resultants were produced together with joint moments. Susanka then reported analyses of two activities, the pole vault and the shot put, in terms of the kinetic parameters calculated. This study is also notable in that Susanka is one of the few European researchers engaged in developing segmental analysis techniques and publishing results in this area.

Koniar(1973) has used a slightly different method of analysis of segment motions. He used electrogoniometry and chronography as the methods to determine angular speeds in joints and the initial speed of whole-body movements. The movements analyzed were flexion and extension in the leg joints, and the whole body motion in the vertical jump. Among the findings of this study was that the height of the vertical jump was dependent not only on the timing of the angular speeds at the joints, but also on the summation of these speeds. He found that the peak velocities of the hip, knee and ankle joint extensions occurred in 'one moment', or at virtually the same instant (Koniar,1973:428). The author named this special summation of movements 'the principle of superposition of angular speeds in joints', and he concluded it reflected an exceptional functional ability in highly skilled athletes. These findings are not in agreement with those of Plagenhoef(1966), who found that the peak velocities of the joint motions were sequential, with the proximal segment reaching the peak velocity earliest in the activity.

Nubar and Contini(1961) developed a mathematical model of the human body to illustrate their principle of minimum effort in human motion. This principle was stated by the authors as follows: "A mentally normal individual will in all liklihood move (or adjust his posture) in such a way as to reduce his total muscular effort to a minimum, consistent with the constraints". Their model was a two dimensional representation of the human figure, made up of only five segments, and the physical properties of the segments are estimated from average values for these parameters. The equations of motion are written in the form of five moment equations, one for each segment, each containing one of the nine unknowns in the system (one of the five segment inclinations, or one of the four unknown joint moments). The equations are further simplified by assuming the static case for the body model, so that all second derivative terms are dropped from the equations. The solution to the equations is several equilibrium positions in which the moment terms are minimized, thus satisfying the constraint. The authors then diagrammed these positions for the five segment model, and it appeared that these mathematically derived positions were very awkward in terms of human comfort or esthetic value. These authors concluded that it may not be practical to attempt to simulate an ideal human posture, since the human body does not really behave as a series of rigid segments.

A similar study to the above was a mathematical model of human gait (Oberg, 1974) in which the body was modelled as a series of seven segments moving through a single plane. The instantaneous position of the body was determined by the X and Y coordinates of the endpoints of the segments, and these points provide the input data to the computer program.

The program then calculated the velocity and acceleration of each of the points of interest, and the moment and force functions are also calculated. The program also produced plots of the model executing a complete cycle of the gait, with certain of the parameters altered. The author suggested that this program may form the basis of a more complex model in which the design was extended to a three-dimensional model, or to one with more of the body segments included in the analysis.

Dillman(1971) used the technique of segmental analysis in a recent study, in which he examined the relative motions of the three leg segments during the recovery phase of sprint running. He simplified earlier segmental models by replacing the muscle force acting to rotate a segment at a joint, by an equivalent joint force and couple acting at the joint. This step simplified the computational procedures required to estimate the muscle forces acting to rotate a joint during a movement, by elimination of one of the unknowns in his equations--the distance from the joint center at which the muscle force acts. Using this model for segmental analysis, Dillman was able to estimate the direction and magnitude of the torques acting at the three joints of the leg during recovery. This enabled him to estimate the amount and type of muscle action occurring in the muscles of the lower extremity during this activity--some of which are quite unexpected in terms of the direction of motion of the segment.

Cavanagh and Gregor(1975) also used this method of analysis in an examination of knee joint torque values during the swing phase of normal treadmill walking. They assumed that the shank and foot were a single rigid body attached to the thigh by a frictionless pin joint. Using this model they calculated the torque at the knee joint; and compared these torque values with the integrated EMG recordings of the muscle activity occurring at this time. They found a marked similarity between the changes in the integrated electromyograms and the net torque-time curves, indicating there was some accuracy in their methods of measuring joint torques.

Some of the more ambitious biomechanics researchers have focussed their energies on the development of whole-body mathematical models to study certain activities. Chaffin(1969) developed a computerized biomechanical model which viewed the whole body as a series of seven links from which reactive forces and torques were computed at each articulation for several different lifting skills. One of the major purposes of his investigation was to estimate the stress in the lower lumbar spine, especially with the addition of external loads on the hands. Another aspect of performance studied was to evaluate the effects of muscle strength in various muscle groups on the ability to lift and hold certain loads. The model described in this study was primarily a static model, so that the investigators were able to analyze only stationary positions, or slow movements which could be described as a series of static positions.

Another problem which has plagued researchers in biomechanical analysis is that of three-dimensional movements between the two articulating surfaces of a joint. The investigator usually has to assume that the joint is a pinned joint which allows movement in only one plane, when in fact there are other motions occurring between these surfaces. Kinzel, Hall and Hillberry(1972) have designed a mathematical system to measure the total motion between two body segments. They noted that all joints of human and animal bodies permit six degrees of freedom although the motions in one plane may be very small. They were able to measure the extent of this rotation using a method of matrix algebra to facilitate data reduction oThe system outlined by these investigators permitted both the study of the relative motion between two body segments, as well as the detailed study of the relative motion between the two articular surfaces of the joint between segments.

Miller(1970) also utilized the principles of segmental analysis in formulating her model of the airborne phase of springboard diving. She used a four-segment model based on Hanavan's model of a movable man (Hanavan, 1964), for which she developed a series of equations to describe the motion of this model in the air after leaving the diving board. Whereas Hanavan's model was composed of fifteen segments, Miller was able to describe the motion of the diver adequately using a composite of four of these segments. The work of Miller in this study represents one of the few detailed mathematical models of performance produced by a researcher in physical education, and as such represents a milestone in the field of sports' biomechanics. The input data for the computer program consisted of three-dimensional film data from actual dives performed by highly skilled divers; and the necessary body segment parameters were also measured from these performers. Using this data from actual performances, Miller was able to validate the results of her modelling, and once the model was fairly accurate she was able to alter some of the input parameters of the diver. Using this model, it was then possible to alter the positions of the various body segments in the air, and the computer could then calculate the effects of these alterations on the ensuing performance. Although the value of such modelling to our understanding of the components of skilled performance is unquestioned, no similar studies have been attempted since that time--undoubtedly a tribute to the capabilities of this investigator. Possibly in the future, when physical educators are more highly skilled in the techniques of mathematical analysis and engineering mechanics, more such ambitious studies will be attempted.

Gallenstein and Huston(1973) devised a mechanical model based on Hanavan's(1964) model of the human body. This model was used to simulate the motions of a swimmer executing several strokes and kicks. The arms were modelled as the frustrums of elliptical cylinders and cones connected by pins and ball-and-socket joints. Flat elliptical plates represent the hands,as proposed by Hanavan,1964. Different angles and velocities for the three segments were input data into a computer program written to simulate the breast stroke, and some estimates were derived of possible optimal angles of the upper limb for this skill.

Several authors have focussed their attention on the measurement of rotation of body segments around their longitudinal axes. This is an important problem in the quantifiaction of human movement, and one that has no consistent solution even today. Eberhart and Inman(1951) have described one solution to this problem, in that they inserted pins into the lateral aspects of the joints of their subjects. They then filmed these subjects during locomotion, and measured the different lengths of the pins at various stages in the gait cycle. Although this technique did result in reasonable estimates of the rotations of the leg segments, it was painful and caused some discomfort to the subjects. The authors noted: "--the possibility that some of the motions are suppressed due to the discomfort of the subjects." Although this technique may have some value in a clinical situation, even then the results likely do not justify the procedure.

Panjabi and White(1971) have described a method of three-dimensional mathematical analysis of the rotation of the spine, which may be adapted to provide a general three-dimensional analysis procedure. This analysis took two forms: Euler's method,(based on the Euler method of solution of differential equations) which was found to give unreasonable results or none at all when actual experimental data were employed; and a vector method specially modifieThey also suggested a method of reporting the rotations of the segments of the spine in terms of helical motions, used if bodies are of irregular shapes and sizes and it is not then possible to compare their translation components of motion. They noted that this experimental technique and mathematical analysis can be "--productively applied to other joints, especially some of the more complex ones like the shoulder, hip and ankle".(1971:210) However, their technique of analysis once again has limited value in the analysis of in vivo movements due to the necessity for extreme precision in measurement the locations of the anatomical landmarks on the vertebrae. They used actual vertebrae in their study, which were carefully marked with steel pins and were then x-rayed and measured from a film analyzer. This technique obviously has little practical significance for the analysis of joint motions as they occur in sports' skills.

Measurement of rotation of body segments was also the topic of a paper by Ramey and Nicodemus(1977). They noted that much of the literature of sport' biomechanics has reported angular kinematic values based on single plane analysis which usually give erroneus values. This is due to the fact that analysis is most often carried out from single plane film data, when the rotations are actually occurring in three-dimensional space. They described the procedures of transforming reference frames for each type of rotation which is occurring in the segment, so that the angular velocity can then be reported in terms of the components of angular velocity around each one of the three primary axes: X,Y, and Z. They suggested that all angular velocities should be reported in this way, although the methods require a knowledge of three-dimensional vector mechanics, as well as the ability to produce accurate spatial coordinates. It is undoubtedly the latter problem which has prevented sports' biomechanists from reporting rotations in the suggested manner.

Analyses of Ballistic Skills

Although the use of the segmental analysis techniques of engineering in sports' biomechanics is relatively new, there have been several researchers who have published studies of this nature. This technique as applied to ballistic movements has been outlined in detail by several of these researchers(Dillman,1971; Miller and Nelson,1973; Youm,et al.,1973; Roberts,et al.,1974; Zernicke, 1977). The steps to be followed in applying this technique to skills' analysis are as follows:

1. Filming the activity and reduction of film data by some

type of digitizing process.

2. Design of a mathematical model for use in analysis of the film data.

3. Estimation of body segment parameters.

4. Construction of a computer program which smooths the input data, and calculates accurate estimates of the kinematic and kinetic parameters of the activity.

5. Production of graphs of these calculated parameters, and interpretation of these graphs on the basis of the actual film records of the activity.

One of the most popular activities which has been analyzed by these techniques is that of kicking, undoubtedly due to its' simplicity in terms of the amount and range of motion involved. Roberts and Metcalfe(1968) noted that one of the most important joint motions in this skill was that of pelvic rotation, which they estimated from film taken from an overhead camera. The other movements of most importance in this skill were hip flexion and knee extension just prior to contact with the ball. They found that as the thigh passes the perpendicular position, its' angular movement begins to slow and almost stop; at which point knee extension starts and accelerates. This knee extension which does not start until the thigh is past the perpendicular is the chief contributor to speed at and through contact. They also found that foot speed 15ms. before contact is 18 to 24 m/s; and that the resulting ball speed is 5 to 7 m/s faster that the foot. These authors suggested that 'trailing' of the distal segments during these activities may lengthen the agonist muscles and thus provide for a more forceful contraction via the stretch reflex (1968:318).

Youm,et al.(1973) devised a quantitative method for analyzing a simulated kick motion. They developed a mathematical model of the forces and moments acting on the leg segments during the skill of kicking, and a computer program was written to simulate this model. The authors could then alter the input parameters, and then graph the effects of these changes on the kinematic and kinetic parameters of the motion. The study included a series of graphs illustrating the displacements, velocities, accelerations, and forces and moments acting at the joints during this skill.

Roberts,et al.(1974) continued with this analysis of the skill of kicking, with the objective of attaining more accurate estimates of limb segment accelerations and to then produce more accurate estimates of the muscular forces involved. They attempted to compare vertical ground reaction forces calculated from film displacement measures with vertical reaction forces recorded by a force platform. They found the forces calculated from these two independent means deviated by only 6 per cent, and this disagreement occurred where the force platform record deviates from a smooth polynomial shaped curve. They attributed this lack of agreement to the error inherent in the techniques of curve-fitting, since the curve did not describe the data perfectly. Another reason for the lack of agreement between the two sources may be due to movement of the trunk, which was not accounted for in the mathematical modelling. The authors concluded that "Cross-comparison and verification of results obtained by different methods appear to be almost essential"(1974:162).

A further study of football kicking was carried out by Macmillan(1975) on the kick used in Australian rules football. Although there seems to be a preponderance of kicking studies published in the literature utilizing similar techniques and methodology, it is notable that all of the above studies were carried out at the same laboratory--at the Department of Physical Education for Women at the University of Wisconsin, Madison. It is likely that an analysis technique for this skill has been developed over the years by these investigators. Macmillan's study focussed on determining the factors which affect the path of the kicked football to the greatest extent. As well as calculation of the linear velocities of each of the segmental endpoints, statistical methods were used to determine that angular velocity at the knee was the major determinant of linear foot velocity. The most notable finding of this study was that the foot velocity had little relationship to the resultant ball velocity, and was consistently lower than ball velocity. Macmillan suggested that the question of momentum transfer at impact from foot to ball needs further study to determine the exact relationship between these two factors. Kermond and Konz(1978) conducted a similar study to that of Macmillan, and they also concluded that the most important factor in football kicking distance is the force transferred to the ball at impact.

Upper Extremity Analyses

There have been numerous analyses of the upper extremity published by various researchers, and each of these described a slightly different method to analyze the motions of this limb. Although most of these analyses are single plane, two dimensional analyses, several authors have attempted to develop a method of three dimensional analysis of arm movements. These latter studies have generally been developed in an attempt to measure abduction-adduction of the arm segments, as well as to measure rotation of the arm segments around their longitudinal axes.

The commonly accepted procedure of graphing the angular displacement data with respect to time, and then determining the slope of the curve to calculate velocity was used as long ago as 1931 in a study by Fenn, Brody and Petrelli. They then used the slope of the velocity curve to determine acceleration. The graphs of each of these curves for a simple arm-swinging motion were then superimposed upon one another, and from these curves the relative muscle tensions at certain points in the arm swing were estimated. Although this was a rather rough method of estimating these forces, the principle behind their method for estimating these forces is still in use today.

One of the earliest attempts at a detailed analysis of the motions of the upper limb was an attempt at three dimensional analysis (Taylor and Blaschke, 1955). It described a single camera technique, in which the subject was photographed from each of the three primary directions while sitting upright in a 'standard posture chair'. The limbs were measured as accurately as possible from the subject, and these same limbs were measured from the photographic data. Using carefully marked anatomical landmarks, the angles at the joints in various positions were calculated by the use of a device called a Kinematic Analyzer. This apparatus was "--a half scale system of joints, members, and scales which is capable of reproducing the major joint rotations of the shoulder, arm, forearm, and hand"(1951:1263). Using this mechanical simulator, it was then possible to estimate the angular displacements of the arm segments, as well as the amounts of pronation-supination occurring in these movements.

Pearson,McGinley and Butzel (1960) described another method of analysis of the motion of the upper extremity in the X-Y plane. They regarded the upper limb as consisting of only two segments--the upper arm and the lower arm plus hand. Angular values were calculated for the displacements of each of these segments throughout a particular motion. The arm motion analyzed in this study consisted of an underhand throwing motion similar to that used in the present study. The body segment parameters used were calculated empirically by the authors on the subjects they tested. Weights of the hand, forearm and upper arm were determined by the water displacement method. Moments of inertia were estimated by constructing models of the limbs, swinging them as pendulums, and determining the periods of the pendulums. The intent of this model was to compute the forces and torques at the shoulder and elbow joints, to derive an understanding of the muscle actions involved at this joint as well as the amount of strain at these joints. Although the authors were able to compute values for these parameters, it is likely that these values were of questionable accuracy. The main reason for this is their assumption of the lower arm plus hand as a single segment. Since there is considerable movement at the wrist joint in most movemetns of the arm, the assumption of these two segments as a single rigid body is in error. Movements of the hand segment would erroneously be calculated as movements of the entire segment, so that this assumption should not be made.

Morrey and Chao(1976) described a method of measuring the passive motion of the elbow joint using a three dimensional vector analysis technique. They used the frozen upper extremities of two cadavers to examine this elbow motion, with the humerus firmly fixed to a stationary object with pins. The rotational motion of the forearm with respect to the humerus was expressed in terms of the Eulerian angles which uniquely describe the components of three-dimensional elbow motion. The first angle is the flexion-extension angle, the second angle is the carrying angle,(abduction and adduction at the elbow), and the third angle is that of axial rotation. The investigators determined the following facts regarding the motion of the elbow: as the elbow flexes, the carrying angle varies linearly; in extension there is a valgus angulation and the forearm rotates axially on the humerus during flexion.

Youm, Flatt and Sprague(1977) conducted a similar three-dimensional joint kinematic analysis of two rigid links, in that they were also interested in measuring rotation of the elbow joint. They used 3 non-collinear spark gaps to determine the position of the radius and ulna during the motions examined. They reported equations to determine the angular velocity of the movement of the radius around the ulna in pronation and supination. This rotation was measured around two different axes and was found to be different depending on the axis measured. They also described the position of the main axes for forearm pronation-supination, and elbow flexion in relation to the major bony landmarks of the upper limb. This study represented one of the few attempts available to analyze the motions at the elbow joint using the fundamental principles of three dimensional rigid-body kinematics.

Youm and Yoon(1977) have recently devised a mechanical model for two dimensional analysis of the motion of the upper limb. As a mechanical model for this investigation, a four-bar linkage model was employed by introducing a fictitious link between the shoulder joint and the end of the hand, so that the open linkage formed a closed linkage. To derive input data for their analysis, an experiment was conducted using photographic technique with L.E.D.s. attached to the hand and shoulder. A 35 mm slide photograph was taken perpendicular to the motion at various pulse rates of the L.E.D.s, and at the same time the ground reaction was recorded by the force plate which was mounted underneath the subject's feet. The joint forces were then calculated at slow, moderate, and fast speeds, and they found that in the motions of slow and moderate speed, the joint forces were close to their segments own weight. When the speed of motion was increased, the joint forces increased quite dramatically.

Ayoub, Walvekar, and Petruno(1974) also developed a biomechanical model for upper extremity motion analysis in three dimensions. They used the basic equations of Newtonian mechanics to calculate the forces and moments at the joints, since "At any instant in time a rigid body in motion will be in dynamic equilibrium if the sum of the moments due to external forces acting on the body are equal to the rate of change of the angular momentum of the body" (1974:1142). They used the Euler angles to specify a body segment orientation in space at any time during the motion, relative to an X,Y, and Z coordinate system. The angular velocity and acceleration of the segment could then be expressed as a function of the first and second derivatives of the segment's Euler angles. They used the anthropometric data from five adult male subjects performing various arm movements to attempt to verify the application of their model. They found that their model broke down at certain arm angles throughout the range of motion, and the equations did not adequately describe the movements. They stated: "In general, it must be concluded that the model as presently constituted is insufficient for predicting human motion characteristics". It is apparent that the complexities of movement of the human body are such that mathematical modelling of these motions is extremely difficult, and often leads to failure.

Jacobsen and Mann(1973) developed a series of equations which were designed to estimate the torque produced at the shoulder joint during a simple flexion motion. The predictor equation was known as the VMG (Vector-Myo-Gram) equation, and it's input consisted of the segment position vectors, the joint velocities and accelerations, and the integrated EMG signals from 9 shoulder muscles. They found that the curves of estimated shoulder torque vs. actual shoulder torque were very similar, so that this model may be used as a fairly accurate predictor of joint moments.

Plagenhoef(1971) also described a model which could be used to calculate the kinematic and kinetic forces acting on the upper extremity. Although Plagenhoef did not specify that the 3-segment model he described was indeed the upper extremity, the forces acting on all body segments are similar so that the model could be generalized to represent the arm. Andrews(1974) also described a mechanical model of the forces which are acting on body segments during the performance of a dynamic activity, which could also be generalized to represent the upper limb.

Ray,et al.(1951) examined the actual movements occurring in the bones of the lower arm during the movements of pronation and supination around a fixed axis of rotation. The axis of rotation was varied by fixing the epicondyles of the humerous by pins. The motions of the two bones was examined by the use of X-rays, as well as by electromyograms of the muscular activity occurring during these motions. They found that under ordinary circumstances the ulna is abducted during pronation and adducted during supination, which is conatrary to a common belief that the ulna is stationary during these actions, and the radius simply rotates around this fixed point. They stated: "--although limited pronation and supination can occur with the ulna remaining stationary, under ordinary circumstances the distal end of the ulna moves laterally as the radius travels medially during pronation, and that during supination the ulna moves in the opposite direction." (Ray, et al.,1951:996)

Another study which was concerned with lower arm rotations was that of Chao and Morrey(1978), who attempted to measure the rotatory components of elbow motion under passive flexion. These investigators once again used cadaver limbs in their experiment, whereby the anatomical landmarks were located by steel pins, and the bones were x-rayed during the motion of interest. In this study the bones were photographed from two views which were perpendicular, and the spatial coordinates of several points of interest were calculated. The three-dimensional rotation of the forearm with respect to the humerus was measured based on Eulerian angles. This study was conducted primarily for use in the development and refinement of elbow prostheses, although the mathematical techniques may be of some value in analysis of other activities.

As can be concluded from the preceding sections of this review, little has been done in the development of techniques for the analysis of the arm motions in vigorous activities. The vast majority of the studies published are of a clinical nature, and are carried out on cadaver or skeleton parts. This method also allows the investigator to implant numerous wire and pin markings into the specimen, and so the measurement of anatomical landmarks is very simple. The error associated with each point measured is therefore relatively small, so that the mathematical techniques used for analysis often work very well. However, because the location of spatial coordinates often requires the use of an approximation technique, if the error associated with the coordinates is too large the technique fails. Most of the mathematical analysis techniques published in these studies simply will not work with data derived from film of high speed body movements. It is clear that it is left to the researchers in sports biomechanics to develop techniques which are accurate and viable for the type of data which they are able to produce.

Data Smoothing Techniques

Since there is always a certain degree of error associated with displacement points calculated from film data, it is necessary to use the methods of numerical analysis to 'smooth' these data points. There are several different methods of data smoothing currently in use in biomechanics research, each of which has had a short-lived period of popularity and has then been replaced by a newer method. For example, early researchers used manual smoothing methods using a planimeter to draw smooth curves through successive data points (Miller and Nelson,1973). Successive methods, roughly in order of their rise and subsequent decline in popularity, included first central difference methods, polynomial approximation by least squares methods, cubic spline approximations, and digital filtering.

One of the earliest sports biomechanics researchers to attempt to smooth film data was Plagenhoef(1973), and he used a polynomial approximation method. Using the film displacement data, he determined the coefficients of a polynomial which best fit the data points using the method of least squares approximation. The order of this polynomial could be altered depending on the regularity of the displacement data--more abrupt changes in the direction or magnitude of the displacement data resulted in a polynomial of higher degree. This polynomial could then be differentiated once to obtain estimates of velocities of the points for which displacements were calculated; and then differentiated again to obtain estimates of the acceleration between these points. However, it is notable that the motion of the point may be so complex that its' path may not be described by a polynomial of low degree. In cases where the curve is a poor fit to the data points, the calculated velocities and accelerations are often too inaccurate for use in further analysis (Pezzack, Norman and Winter, 1978).

The use of the first central difference methods to smooth film data was described by Widule and Gossard(1971) as simply a method of averaging between data points. Points on either side of a certain data point are taken and a line drawn between them. The slope of the tangent to the curve at the given data point is taken to approximate the derivative. This method was found to be fairly accurate for determining the velocity curves of a motion, but "since errors tend to propagate for the higher order derivatives, the results for measures of acceleration have not been completely satisfactory (Widule and Gossard, 1971:110)".

A more recent method of data smoothing is known as cubic spline approximation, and has been widely accepted by biomechanics researchers (Zernicke et al.,1975; MacLaughlin et al.,1976). This is a method of averaging the displacements between successive data points, so that a smooth cubic curve is drawn through each three successive points. The velocities and accelerations of these points may also be approximated by differentation of the equation of the curve between these points. It has been reported that the acceleration values calculated by this method for film displacement data are much more accurate than those derived from other methods.

McLaughlin et al.(1976) have reported comparisons of the cubic spline method and the polynomial curve fitting techniques. They noted that polynomials were inferior because fluctuations in one part of a curve will affect other parts of the curve, and also because polynomials are quite insensitive to quickly varying data of an otherwise uniformly varying curve. One of the problems associated with the use of cubic spline methods is that the endpoint values for the second derivative are zero. Zernicke et al. (1975:14) indicated that "...three extra data points at the beginning and ending of each data set served to minimize the second derivative zero end point tendency." Both of the above investigators used the IMSL Computer Library cubic spline routine called ICSSCU, and they have suggested several methods of estimating the degree of smoothing to be used with this routine. The most practical method suggested

(McLaughlin,1976) was that of calculating the average error in measurement of distances from film. Since the error in calculating distances was determined by the measurement of two points, it was assumed that the total error was equally distributed between both points. Thus, the error for each point was calculated as the degree of smoothing for each set of data in the analysis. Zernicke (1975) has further suggested that this computed error should be used as input to the program to calculate the second derivative values and these values graphed against time. "If the acceleration curve is smooth, use a smaller error value; and if the acceleration curve is ragged, increase the error (1975:14)".

A more recent technique has been reported by Pezzack, Winter and Norman(1978), and is known as digital filtering. They reported graphs of the acceleration values calculated from film data of a simple movement, and they calculated that this may be the most accurate and reliable method to date of determining acceleration values. They stated (1976:381): "Digital filtering of the raw film displacement data followed by simple finite difference differentiation was the only one of the three techniques studied that accurately reproduced the acceleration time curves recorded from an accelerometer". They found that polynomial curve fitting smoothed the acceleration curves too much, and finite difference differentiation did not smooth them enough.

It should be noted here, however, that not all researchers in biomechanics are in agreement as to the importance of data smoothing techniques in biomechanics research. Chao and Rim(1973) have noted that data smoothing techniques are not always desirable, as they noted: "--since numerical differentiation procedure as applied to the experimentally obtained data would magnify the inherent measurement errors. Besides, the final results usually depend upon what numerical techniques for smoothing and curve fitting were applied" (1973:498). They described a system of mathematical optimization equations to determine the applied moments at the leg joints during walking. They developed a two-dimensional model consisting of two segments, the thigh and the lower leg and foot segment, and they used parameters as measured from live subjects as input for their computer program. The displacements of each of the segments of their model were measured through the various phases of the gait cycle, and from these displacements the values of the moments at each of the joints is estimated. They concluded that this method was more advantageous because it required no numerical differentiation of experimental data, and thus the possibility of "magnifying inherent experimental errors is minimized". (1973:510)

A further problem in data smoothing techniques is that the smoothing technique may obscure true motion characteristics in the motion being observed. There may be quick, radical changes in the motion which are smoothed out by one of these techniques, which may be very important to the skill. Widule and Gossard(1971) suggested that a sudden change in the angular direction of a joint at takeoff could be masked if a curve were passed through that point. The investigator must have a clear picture of the motion that he is analyzing to ensure that such important movements are not obscured.

Kinematic and Kinetic Analyses of Softball Pitching

Few studies were located which included accurate quantified data on the softball pitch. Leviton(1975) described the windmill pitching motion qualitatively, noting that the longer path followed by the arm during this style of delivery may allow more time for the performer to apply force to the ball, and thus may result in greater velocity of the ball on release than in other styles of delivery. Kirby(1969) also described this motion in general terms, although he did provide a more detailed description of the arm motion. "It is important that the pitcher keep his arm in a fully extended position, thus lengthening the lever and increasing his arm and shoulder contribution to the ball's velocity. It is also important that his wrist be hyperextended or cocked during this forward whip...the wrist and ball should trail the forearm until the final wrist snap. This will increase the distance over which the wrist can develop momentum."

Although the skill of softball pitching is mentioned in most books on the sport, as well as in most books on skill analysis, the descriptions are often sketchy and inaccurate. Kneer and McCord(1976) noted in their description of the skill that one of the most important motions in the skill is to "snap your wrist forward and roll the ball off your fingertips". No clear description was given of the exact movement involved in this wrist snap, not in which direction it was most advantageous to roll the ball. As well, their description of the timing of the step of the pitcher is in error, as they stated: "as the hand reaches head-high, begin to lift the opposite foot off the rubber and forward in order to keep your balance (1976:39)." The step begins far earlier in the sequence than is stated here, and in fact the step commences as the hand passes the plane of the body. A further description of the windmill pitch was attempted by Dobson and Sisley(1971), which also contained several inaccuracies. They noted that the pitching arm should be straightened at the highest point of the circular arm swing, because the "straight arm, backward and downward swing adds more power to the delivery. This arm action does not permit a high degree of body rotation, and as a result much of the power for the windmill pitch comes from the shoulder muscles (1971:44)". No explanation was attempted to describe how a straight arm action would tend to inhibit body turn.

Zollinger(1963) provided the only study in which any quantitative measures were calculated on the windmill pitch. She calculated the length of stride, the horizontal velocity of the pitch, the torque of the arm about the shoulder joint, and the torque of the hand-ball system about the wrist joint at release. She found that the velocity of the ball at release was determined by two rotary forces: a torque about the glenerohumeral joint (shoulder) and a torque about the radiocarpal joint (wrist). In fact, she has stated that the velocity of the ball at release was determined by the magnitudes of shoulder flexion and wrist flexion, which may be only partially true. However, no attempt was made to describe the rotational forces around the longitudinal axes of the arm segments, which may likely be the most important torques occurring in the skill.

Three Dimensional Cinematographic Techniques

Cinematography has been the primary tool used to examine quantitative external mechanics of all types of human motions (Miller and Nelson,1973). It is well known that such motions have been studied in two planes by one camera filming. However, the validity of studies in which film analysis is the primary tool for gathering data has not gone unquestioned. As noted by Penrose et al.(1976): "The validity of measurements obtained by cinematography and other photographic methods depends on the accurate recording of spatial and temporal relations. The relative ease of camera use has deceived many investigators into thinking that film data parameters can be compared directly with the real world. A major problem has been to obtain accurate spatial coordinates of joint centres and other points of interest during the preformance of a motor activity." In most film analysis studies centers of gravity are located and displacements calculated, from which derivatives of velocities and accelerations may be made. However, as Miller and Petak (1973:14) have noted, "Since virtually all human motion occurs in 3 dimensions, a single camera and planar film analysis methods cannot provide a complete quantitative description of performance." There have been several studies published in recent years which have reported various methods of filming movements using two cameras with the intention of synchronizing these film records to produce three-dimensional coordinates of various points of interest. Other researchers have utilized three cameras to collect film data from which to derive spatial coordinates, normally with one of the cameras being oriented in each of the three principal planes of action.

Noble and Kelley(1969) utilized a three camera technique to determine the three-dimensional coordinates of a moving ball following the path of a right circular helix. They determined the position of the ball, distance traversed, elapsed time, velocity, and acceleration. The films were synchronized by firing a flash bulb at the beginning of each sequence, and timing of the cameras was accomplished by separately photographing a standard electric timer. One camera was located along each of the X,Y and Z axes, and a horizontal and a vertical coordinate were obtained from each of the three films, resulting in a total of six coordinates for each point visible from all three cameras. The mean of each pair was taken to be the true value. The authors concluded that this procedure was of adequate precision to determine the position of a moving object and the primary values of distance traversed and time elapsed, and their first derivative velocity values. They found that the acceleration values were quite inaccurate, and not useful to include in their analysis of results (1969:645). No explanation was attempted for the inaccuracy of these calculations.

Duquet, Borms and Hebbelinck(1973) described a complicated method of three-dimensional analysis of twisting movements which required film data from two cameras, a side view and an overhead camera. By projecting the images onto a grid placed behind the performer, the actual coordinates of the segments of interest could be estimated. As the authors stated: "By a procedure of graphically manipulating projected anatomical reference points to a common plane, it is possible to determine actual positions in space and obtain dimensions and angles, and, from these, derive covered distances, linear velocities and accelerations as well as angular velocities and accelerations"(1973:175). However, the method appears to require much time consuming messurement and transformation of the original film data, and may not be practical for analysis of any reasonable amount of data.

A further study to develop three-dimensional filming procedures was conducted by Bergemann(1974), who was most concerned with the camera placement which would produce accurate spatial coordinates. The two cameras were positioned so that their optical axes intersected at a common origin point, which was determined by surveying equipment. Equations were derived which were used to calculate the position of several arbitrary points on a coordinate grid. The procedure was found to be useful for the determination of these stationary, defined points, but no attempt was made by the author to expand its' use. A similar study was reported by Penrose et al.(1976), in which they investigated the positioning and alignment of cameras with and without intersecting alignment of the optical axes. They studied three camera alignment positions, with the cameras placed in different positions with respect to the origin and the point of intersection of their optical axes. The magnitudes of error in all three filming situations were similar, "indicating that non-intersection alignment of the optical axes should provide information as accurately as the more rigidly controlled camera conditions (1976:6)". The authors noted that this more flexible filming situation would be more useful for collection of data from a game or competitive perfromance, without any appreciable loss in accuracy.

Miller and Petak(1975) described a method of three-dimensional filming in which the three cameras must be placed so that their optical axes intersect at a point near the subject. The three cameras were placed so that their optical axes were at angles of 120 degrees to one another. It was felt that this positioning of the cameras would maximize the number of points visible in the film of any two of the three cameras. Equations were derived to determine the spatial coordinates from the two camera film coordinates. Although this method was reported to produce accurate three-dimensional data it required that the investigators use surveying equipment to locate the optical axis and to ensure that the cameras were horizontal. Van Gheluwe(1974) described a similar technique of three-dimensional filming, where once again the cameras had to be placed in an exact position in relation to the subject.

Black(1977) has recently described a method of three-dimensional filming whereby the X, Y, and Z coordinates are simply read directly from the film analyzer. The two cameras were placed in positions at right angles to one another, with their optical axes intersecting--this point of intersection is the origin of the three-dimensional coordinate system. After some correction for perspective error due to the location of the subject in relation to the origin, the X,Y, and Z coordinates were at right angles to their respective cameras. From one camera the X and Y coordinates were read; and from the other camera the Z and Y coordinates were read. These coordinates were then used to calculate directly the X,Y, and Z displacements, velocities, and accelerations. The film from the two cameras was syschronized by a unique method in which a bicycle was turned upside down in the field of view of the cameras. The rear wheel was marked with several white markers at different intervals, and the wheel was turning during the filming. The film could then be synchronized by the location of the markers as they appeared in each of the film frames.

Dapena(1977) has developed a method of three-dimensional filming by using horizontally panning cameras. The cameras were placed at approximately 90 degrees to each other throughout the field of action of the subjects. The subject was filmed while executing the Fosbury Flop method of high jump, during the last strides of the run-up, the takeoff, and the bar clearance. During this time, each camera was panned horizontally (ie. was rotated about a vertical axis) so that the subject remained within the optical field throughout the entire performance. The cameras filmed independently of each other, and the film records were synchronized by use of critical instants (ie. instant of first touchdown or takeoff). The X,Y, and Z coordinates of landmarks on the body were determined by using several landmarks in the photographic field which were filmed in the background of the jumper. Since the coordinates of each of the background markers were known, their orientation relative to the cameras (some angle theta) was readily computed. A series of markers was then filmed, and the locations of the marks estimated from film data. Dapena found a random error of .5 cm in the X,Y, and Z coordinates, which he concluded was well within acceptable limits for most analyses of sports activities.

Van Gheluwe(1975) has described one of the most common sources of error in attempts at three-dimensional film analysis to be misalignment of the cameras with respect to the intersection of the optical axes. He developed a simple method of evaluating the error on the measured coordinates resulting from camera misalignments. The estimations of deviation errors were based on trigonometric formulas whereby the alignment errors were proportional to the errors in the spatial coordinates, and occurred in the same direction. He suggested that telephoto lenses be used whenever possible, as these will reduce these errors due to misalignment because of their smaller viewing angles and the longer focal length.

A more recent study by Van Gheluwe(1977) has reported a technique in which the cameras may be placed in any position in relation to the subject being filmed. Van Gheluwe has refined his earlier computer program (Van Gheluwe,1974) which is used to transform the two camera film coordinates into three dimensional data so that exact camera placement is no longer necessary. As he stated: "This means that the camera position is now completely free from any restriction: the camera may be tilted at any angle, positioned at any place or distance, etc...Reference points on the steel reference frame are sufficient to reconstruct the spatial coordinates at any arbitrary point in the view field of the cameras." The only necessary step required to coordinate the data from these cameras is that a three-dimensional object be placed in the field and photographed by each of the cameras. The object must have a number of points in each of the three perpendicular planes which are a known distance from the origin of these planes. The author constructed a set of coordinate axes from steel tubing, marked appropriately at regular intervals. The program then calculated a transformation matrix for each of the cameras, and also one for the combined data, and the output consisted of three-dimensional coordinates of a series of points photographed by the two cameras simultaneously. He found that the X,Y, and Z coordinates calculated from this program were accurate to five per cent when a grid composed of known distances was photographed.

However, once the three dimensional coordinates of a point moving in space have been determined it is then necessary to use this data to calculate important kinematic and kinetic data from the film. Much of this computer programming of analysis techniques has been attempted in a recent study by Black(1977), in which she described a three-dimensional filming technique, and she also developed a computer program utilizing the methods of engineering vector analysis to determine velocity and acceleration values for this data. Black also attempted to estimate the magnitudes of angular velocity and acceleration of the segments in some simple skills, but did not attempt to verify these estimates. These estimates were based on the asumption that the rotations occurring were only occurring in two planes, and that the rotation in the horizontal plane was negligible. She assumed that the rotations of the segments around their longitudinal axes were not critical so were assumed to be zero. This assumption is likely not viable for most of the activities analyzed, so that this technique is of limited value to other researchers interested in calculation of angular parameters.

One of the major problems encountered by investigators in attempting to measure spatial coordinates is that of photographic perspective error (Black,1977). Martin and Pongratz(1974:469) stated that "Photographic perspective error has long plagued the researcher attempting to obtain accurate three-dimensional coordinates from two-dimensional film data". They developed formulae to correct for this error, based on their study using film from two 35mm cameras. The cameras were set up with their optical axes intersecting at right angles to one another, to define the spatial coordinate system. They determined the perspective error by comparing actual distances on their reference measure with the distances calculated from film displacement data. These formulae may be used by any researcher to correct the film data from two positioned cameras for perspective error, and in fact these were used by Black(1977) in a recent study.

The problem of producing accurate three-dimensional coordinates of film data has been one of continuing interest to researchers in sports' biomechanics. However, virtually all of the above studies reviewed have validated their procedures by filming a coordinate grid, or a series of fixed reference markers. None of the studies located attempted to locate the spatial coordinates of the joint centers of the body during a vigorous sporting activity. It must then be concluded that there is no useful and accurate procedure presently available to determine the X,Y, and Z coordinates of the body segmental endpoints. This difficult problem is one to which a useful and viable solution is necessary in order for biomechanical analysis to continue to provide answers to questions of technique in skills analysis.

Force Platform Studies

The use of force platform data is relatively recent in the biomechanics of sports investigations. Ramey(1973) has stated: "The force plate has become a useful tool for the study of many types of human motion--the force plate yields some fundamental data and substantially assists in the understanding of the motion involved. In the particular case of the athletic studies the force plate has been used to identify faults in technique and has led to new ways to perform the event." The force platform is basically an electronic sensing device in which a strain gauge or an LVDT is mounted within the platform so that strain on the platform is picked up as a change in the resistance of the device. Many of the platforms in current use are able to record forces in the X,Y, and Z directions, as well as torques about each of these axes (Miller and Nelson, 1973).

One of the early reports summarizing the use of this technique was reported by Payne(1968). He noted that the force platform was a valuable tool to examine the forces exerted against the ground during a performance. However, he warned that the natural frequency of the platform is excited by the sports' performance and the tracings may not be accurate for some activities. Miller and Nelson(1973) have also noted some difficulties in force platform use, such as the difficulty in securing the platform properly to attain proper damping. Also, they are limited in size because of their complex construction and instrumentation, and they are limited to a certain frequency response level. In a more detailed study, Payne(1968b) described the use of the force platform in examining the ground reaction forces in a number of activities, including the sprint start, the running stride, shot put and weight lifting. He noted that these tracings could provide the coach with valuable insight into faulty technique in some of these skills. In the shot, for example, there was a change in the value of the horizontal thrust from positive to negative, indicating a shift in the drive from the legs from the rear leg to the front one. The timing of this shift in relation to the throw can tell the coach a great deal about the application of forces by the thrower, and the timing of these forces.

Lamb and Stothart(1977) conducted a vertical jump study in which they compared the force platform method of determining center of gravity kinematics and kinetics, and the method of calculating these parameters from film data. They found that there were no significant differences between the parameters calculated using either of these two methods and so the force platform provides an accurate estimate of the forces exerted against the ground.

Probably the greatest value in force platform data in cinematographical studies is as a check on the accuracy of the digitized data. As the shape of the force curves approach those produced from calculations from film data, so the data become a more accurate representation of the application of ground forces during the skill. Since the calculation of ground forces is based upon the determination of acceleration from film coordinates, this is also a test of the amount of error present in the digitized data. Similarly, a large discrepancy in the shape of these two records may indicate that the data calculated from the film has a large amount of error.

CHAPTER III

PROCEDURES

Experimental Procedures

This chapter deals with the experimental procedures undertaken by the investigator in this study, as well as the techniques of data analysis employed.

Pilot Study

A pilot study was carried out in November, 1977 to verify the experimental procedures to be used in the final project. Two subjects were originally used in this study,one male and one female, both scheduled to participate in the final study.

The filming of the subjects was conducted in the strength laboratory of the Faculty of Physical Education. The photographic field consisted of a force platform mounted on a larger platform, from which the subject pitched the ball into a large cargo net suspended from the ceiling of the laboratory. A target was indicated on the cargo net to approximate the size of the strike zone during the game of softball. Only those pitches which entered the strike zone were chosen for analysis. This precaution was taken to ensure the analysis of pitches which would be good pitches in a game situation, and would not include 'wild' pitches which may involve incorrect joint movements.

Two Photo Sonics 1PL 16mm movie cameras were placed at two positions in the laboratory with their optical axes almost at right angles to one another. The cameras were at a maximal distance from the subject within this relatively small area. Camera 1 was placed so that the optical axis was perpendicular to the direction of the pitched ball, which was also at right angles to the direction of the major joint motions of the pitcher. Camera 2 was placed in front of the performer, and slightly to the right of the direction of the pitch. The two cameras were set so that the exposure time was as short as possible with the available lighting. In particular, the exposure time was calculated to be .00125 seconds with the shutter angle set at 45 degrees. Since the light in the laboratory was rather poor for high speed filming, the film was 'pushed twice' during development. This still resulted in rather dark films.

Both cameras were set at an operating speed of 100 frames per second (fps), and both were connected to a timing light which placed a mark on the films at every .1 second interval. The two films were further synchronized by use of a flash signal, operated manually at the beginning of the pitch to be filmed. The flash device was operated by an assistant during the actual filming, and this flash served as the signal for the subject to begin the pitching motion. The assistant was in a position behind the subject so as not to interfere with the activity, but so that the flash was visible in each of the camera fields. In this way the film from each of the cameras could be analyzed from the same point in each pitch, and the data from the two films could be converted into a single set of three-dimensional coordinates by the use of an appropriate computer program.

The film from the pilot study was found to be too dark for detailed analysis when shot under these experimental conditions at 100 frames per second. However, part of the film was shot at 30 frames per second, and resulted in satisfactory exposures. This film was subjected to some preliminary analysis to ensure that the necessary parameters could be determined for this study. Several decisions were made on the basis of the findings of the experimental study, which affected the subsequent filming of the subjects. One, was that the available lighting in the strength laboratory was inadequate to film at 100 frames per second, and that more lighting would have to be made available in the final study. Secondly, this area was too small for the cameras to be placed an adequate distance from the subject to avoid large perspective errors. A larger indoor filming area had to be located. Thirdly, it was found to be difficult to measure the rotation of the arm segments around their longitudinal axes from the front view camera. Since the markings on the arm were obscured from the camera view by the pitcher's body, a more advantageous position for the second camera was found to be to the rear of the subject.

Testing Apparatus

Filming Equipment

Two Photo-Sonics 1PL 16mm cameras were used in the present study, in which the frame rate could be altered from 1 to 500 frames per second. The cameras are motor-driven, so that the frame rate remained relatively constant (+ or - 1%) throughout the filming session. The two cameras were calibrated by using a strobe light set at 100 flashes per second, which was then synchronized with the camera shutter. The two cameras were attached to a single Photo-Sonics Timing Light Generator electronic timer, which was set to mark each film with a light flash at every .1 second interval. This timing device was also used to synchronize the film records of both cameras, as described in a later section.

Each of the cameras was equipped with an Angenieux 12-120 zoom lens, adjusted to the desired focal length.

In order to utilize the three-dimensional computer program to analyze the film data from two cameras, a metal 'tree' was constructed. This tree consists of six one-meter pieces of copper tubing fixed into a wooden block forming an orthogonal triad of axes, emanating from a common origin. These axes were then divided into 10-centimeter divisions by marking them with black tape. The tree was then attached to a wooden stand so that it would remain rigid at the site of the filming. This tree was then placed in position on the site from which the subject was to pitch the ball, and was then photographed by each of the two movie cameras. The tree was filmed at regular intervals throughout the filming sessions, in case the cameras were inadvertently moved during the actual filming.

Force Plate

Three pitchers were filmed in the dance studio. Each of the pitchers pitched the ball while standing on a force plate. The force plate used in this study is a commercially manufactured plate, a Stoelting's Model #19570 which was purchased by the Physical Education Department six years earlier. This platform uses 'Linear Variable Differential Transformers' (LVDT), and is supposed to be linear in all three axes. The force tracings attained from this plate during the pilot study were found to be inconsistent, attempts were made to correct this for the final study. The subjects were asked to begin the pitch with both feet in contact with the force platform, and during the actual pitch the subjects took a step forward onto the left foot. Therefore for most of the duration of the pitch, the performer had one foot in contact with the force plate. Since the other foot was free in the air for most of the force-producing phase of the pitch, the forces recorded by the force plate were representative of the forces exerted by the pitcher during the major portion of the delivery of the ball.

The forces exerted on the force platform were recorded by a Honeywell model #1912 visicorder. The tracings of the exerted forces, recorded by the Honeywell, were synchronized with the appropriate film records by means of the same Photo Sonics timing light which was attached to both cameras. Thus it was possible to compare the forces calculated from the film records to the forces recorded by the force platform tracing, at any particular instant in the performance.

Film Analysis Equipment

The preliminary analysis of the film was carried out with the aid of a Lafayette 16mm Analyst projector. It was possible to carry out considerable preliminary temporal and spatial analysis by using the attached digital frame counter. Editing and synchronizing of the films by ink markers was also carried out by a Traid Model V/R-100 film analyzer, which also enabled the investigator to record the positions of various points of interest during this phase of the analysis.

The film records were analyzed by digitizing body segment endpoints with a Bendix 9864A digitizing board attached to a Hewlett-Packard 9825 programmable calculator. Since the investigator had spent a good deal of time in digitizing segmental endpoints from movie film, the reliability in locating joint centers was considered to be very high. However, this reliability was checked on several sets of data by using Pearson's Product Moment Correlation between sets of measures. The segmental endpoints for the three arm segments were digitized, and input directly into the HP 9825 where a program was stored to produce segmental inclination values. The test-retest reliability of these angular values was found to be at least r=0.97 for all sets of data tested. The required endpoints were digitized for each frame of interest, and the film records were stored on magnetic tape for further analysis. The data was then read into the large time-sharing computer system at the University of Alberta, which was operated by an Ahmdahl 460V/6 computer. Much of the data analysis was also carried out by the HP 9825 which was progammed to calculate several of the parameters of interest in the pitches.

Subjects

The subjects used in this study were four highly skilled softball pitchers,two male and two female. All of the subjects were right-handed, so that camera positions and descriptions of the pitch were the same for all. All four performers could be classified among the top pitchers in the Province of Alberta, since all four had played in a number of National Championships. Two of these pitchers (1 male and 1 female) had been chosen as Canadian All Stars on at least one occasion, and so could be classified as among the best in the country. All were currently members of a Senior or semi-professional softball team, although the testing was done in the month of February when none of the pitchers were actively involved in playing. It is possible that the ball velocity measures may have been considerably higher if the testing had been done in mid-season, but for such highly skilled performers it is unlikely that the technique would alter a great deal. Following the actual filming session, each of the subjects was asked to complete a questionnaire describing his or her softball pitching history. This history provided the investigator with greater insight into the actual skill level of each of the performers.

Subject Preparation and Measures

As each subject arrived at the filming site, the following anthropometric measures were taken by the investigator: standing height,weight, upper arm length, biceps girth (flexed and relaxed), lower arm length, wrist diameter, hand length, and hand span. These measures were taken to enable the investigator to determine more accurate estimates of the moment of inertia and radius of gyration of the segments of the pitching arm.

The subjects were further prepared for filming by placement of tape strips and markers on the pitching arm, to assist the investigator in measuring the rotation of these segments. The following tape strips were placed on the subject: (1) from tip of acromion process to lateral epiepicondyle of humerus, (2) from median border of axilla to medial epicondyle of the humerus, (3) from lateral epicondyle of humerus to styloid process of radius, (4) from medial epicondyle of humerus to styloid process of ulna, (5) around diameter of wrist (6) from styloid process of radius to tip of the thumb (7) from base of the lunate to the tip of the III phalanx. As well as these strips of black tape, each of the bony prominences marking the centers of the joints were marked with a circle of white tape in order to allow for more accurate estimates of the position of the joint centers.

Filming Procedures

The filming of three of the subjects was conducted in the dance studio of the Physical Education Building in February, 1978. The fourth subject was filmed outdoors a few weeks later. All procedures for this subject were the same as described herein, except for the location of the filming, and the absence of the force platform. This area was selected for the actual filming because of its' larger size, the black curtain along one wall, and especially for the large number of floodlights located on the ceiling, usually used for dance performances. The side view camera was located exactly 50 feet 9 inches from the performer, and at right angles to the direction of the pitch. The pitchers performed from a position with the back foot placed directly in the center of the the force plate, which was located in a larger force platform, and threw the ball at a thick gymnastics mat placed against the wall of the room. No attempt was made to measure the accuracy of these pitches, although the skill level of the performers was such that no really 'wild' pitches were filmed.

The other camera was placed to the rear of the peformer, at an angle of approximately seventy degrees to the side view camera. This placement was chosen because of the necessity to film the joint markers as long as possible during the actual release of the ball. This camera position was found to be optimal when different camera positions were tested in an earlier film of the rear view of the pitcher. This camera was placed exactly forty feet from the subject, which was the maximum distance it could be positioned in the filming area.

The two cameras were set so that the exposure time was as short as possible with the available lighting in the dance studio, so as to minimize the blurring of the ball during release. Kodak Ektachrome #7240 Tungsten film, with an ASA rating of 125 was used. The exposure time was calculated to be .000833 seconds with the shutter angle set at 30 degrees, and the film was 'pushed one stop' during development. The fourth subject who was filmed outdoors, was filmed using Kodak Ektachrome #7239 Daylight film, with an ASA rating of 160. Both cameras were set at 100 frames per second, and were calibrated by use of a strobe light so that the camera speeds were exact. Further information on filming techniques may be found in Appendix A. The two films were further synchronized by the use of a timing light which placed a timing mark on the edge of the film at any set interval. This timing light was used to synchronize the films by the following method: the cameras were started at the same time by a signal from the investigator; a verbal signal was then given to the subject to begin the pitch--on this verbal signal the timing light was switched from 100 flashes per second to 10 flashes per second by one of the cameramen. Thus each film was clearly marked as to the point at which the pitch began, simply by the decrease in the number of timing marks. This method was found to be an effective means of synchronizing the film records, which was necessary for the three-dimensional analysis procedures.

Ten trials of each subject's 'fastest' softball pitch was filmed, and the best five of these trials were selected for study. Since one of the prime characteristics of good pitching is the velocity of the pitch, the five trials in which the greatest ball velocity was attained were chosen for analysis. Since there were four subjects in the study, taking the best five trials for each one resulted in twenty separate pitches being analyzed in a preliminary way. However, since the subjects were all very highly skilled, there was found to be very little variation between the pitches for a single pitcher. Since it was clear that analysis of five pitches by each pitcher would be an unnecessary duplication of data, it was finally decided to analyze in detail only the two fastest pitches of each of the four pitchers. In this way, only the most highly skilled movements of these skilled performers would be subject to detailed analysis.

Force Plate Procedures

The subjects were instructed to pitch each ball with the back foot placed on the force platform. The forces exerted by the performer against the force platform were picked up by the strain guages within the platform, and these signals were amplified and appeared as tracings on the Honeywell visrecorder. This tracing allowed comparison of the ground reaction forces calculated from the film data with the force plate recordings, so that a check was available on the accuracy of the accelerations computed for the body mass center.

The force plate data was synchronized with the film data for each pitch by means of the flashes from the timing device attached to the cameras. This timing device was also attached to the Honeywell recorder, and was recorded as an event marker on the tracing of the forces recorded from the force platform. In this way the three independent sets of data (that from camera 1, camera 2, and the force plate) could be synchronized, and the records of each pitch could be analyzed from three different data sources at any particular instant in time.

Analysis of Data

The data collected for this study have been analyzed under the following nine classifications:

1. Subject Pitching Data
2. Pitching Parameters
3. Body Segment Parameters
4. Ground Reaction Forces
5. Angular Kinematics
6. Linear Kinematics
7. Single Plane Kinetics
8. Three Dimensional Analysis
9. Three Dimensional Angular Velocities

Subject Pitching Data

To provide a basis for description of the entire pitching motion, the film of each pitch was analyzed from the beginning of the windup to the end of the followthrough. Since the entire motion took up to 150 frames to complete, every fifth frame was digitized for the whole body calculations. The film was digitized by the investigator using the Bendix digitizer board and an HP 9825 programmable calculator. Since there were two cameras filming each of the pitches, each of the pitches analyzed had to be digitized twice, once from the side view camera and once from the rear view camera. The digitized segmental endpoints were stored on magnetic tape by the HP 9825, and were later transferred to the Ahmdal 460/V for analysis by the mass center programs stored there. Each of twenty-two segmental end points was digitized and the coordinates of each of these points was recorded onto magnetic tape. This data could later be stored into disc files in the computer memory, or could be punched onto computer cards for storage and later assembly into a computer program.

It should be noted here that one of the critical problems in carrying out the present study was the ability to read the digitized endpoints into the Ahmdal computer for further analysis. Since the digitizer board could only be attached directly to the HP 9825 and the points stored onto magnetic tapes, these tapes were only readable by this machine. It was necessary to have a computer program written which would allow the HP 9825 to be attached directly to the large computer, so that the HP would act like a regular terminal and could then send data to be stored in the Ahmdal. This program was eventually provided by the Hewlett Packard programmers, and with this program and some additional hardware (a ROM connector and a high speed line printer) the digitized data was transferred. Some problems were encountered with the actual transfer of the data points, in that the speed of the transfer was too great for the receiver, so that there were numerous errors in the data files which had to be corrected. This was possible because the original data were stored on the cassette tapes, which could be read by the HP 9825.

The segmental endpoints of the upper extremity involved in the pitching motion were digitized separately from the whole-body data. The four endpoints involved in this digitizing process were: the shoulder joint, the elbow joint, the wrist joint and the fingertips. These four endpoints were digitized in two different ways for each pitch. First, the whole pitch was digitized--from a point .40 seconds prior to release to a point .10 seconds after release, every second frame of the film was digitized for a total of 25 frames. Secondly, the pitch was digitized from a point .20 seconds prior to release to a point .05 seconds after release, every frame was digitized for a total of 25 frames. For each of the eight pitches analyzed, then, there were two independently measured sets of data describing the motions of the arm segments, which could be used as a check on the reliability of the digitizing process.

Pitching Parameters

For each of the pitches filmed, the velocity of the ball in each of the six frames following release was calculated by use of a computer program written for the HP 9825. To determine the actual velocity of the ball in each of the pitches, the highest and the lowest velocity estimates were dropped, and the remainder of the velocities were averaged. These velocity estimates were found to be in close agreement, both those between frames for a single pitch, and those between pitches for a particular subject.

Another parameter of the pitch that was calculated for each of the pitches was the time for the pitch. For the purposes of this study, the time for a pitch was the time from loss of left foot contact with the force plate, until the actual release of the ball. This parameter was determined by counting the frames between these two events, using a Lafayette Analyst Projector which was equipped with an electronic digital frame counter.

Another important factor in the softball pitch is the length of the stride taken during the pitch--generally more highly skilled pitchers will take a relatively longer stride. Stride lengths may be compared between pitchers of different sizes by reporting them as percentages of standing height(Zollinger, 1973). The stride length for the pitches of each subject was calculated as the distance from the toe of the rear foot to the heel of the front (left) foot.

Body Segment Parameters

It is of critical importance in biomechanical research to have accurate estimates of the relative weights of the segments being analyzed, as these values are used both in the segmental analysis, as well as in the determination of the mass center using the segmental method. There are several sets of percentage weight data which are in common use in biomechanics research today (Miller,1971;Hay,1973), which are primarily derived from cadaver data. As noted by Plagenhoef(1973), the anatomical data presented by Dempster(1955) has been the most widely used, and modifications of his data may be used to estimate body proportions in the living. The accuracy of these estimates is therefore open to question, as the body proportions of cadavers differ markedly from those of a muscular athlete--and the more muscular the athlete, the larger the magnitude of error. Hay(1973) has reported tables of segmental weights which list slightly different percentages depending on the body build of the subject, but since these estimates were originally calculated from equations calculated from cadaver data, they are still open to question. Widule(1976) has noted that although the accuracy of these percentage values is questionable,particularly in the application to females and children, relatively close approximations of segmental mass can be obtained and values can be adjusted according to what is known about the mass distribution of individuals of different somatotype, sex, and age.

The most recent work in the area of estimating body segemnt parameters is reported in a publication called 'Humanscale', published by the MIT press and compiled by Diffrient, Tilley and Bardayjy (1974). Since these parameters were determined from a large number of live subjects and are likely the most accurate presently available, these were the segment weights and inertia factors used in the present study. This publication includes location of the centers of gravity for each of the segments, and estimates of the segment lengths for each of the segments for subjects of three sizes: large, medium, and small. This publication also included all the above parameters calculated for females, which was unique for a publication in this area. The calculated segment masses and calculated weights are reported in Table I.

The moment of inertia is the resistance of a body to rotation (rotary motion). The moment of inertia of the mass of a body with respect to any axis is the sum of the products of each element of mass and the square of it's distance from the axis. Various methods have been used to determine moment of inertia values of the body and body segments, including pendular methods, quick release method, volumetric determination, and through the use of physical models (Widule, 1976).

Since the moment of inertia of a living body segment cannot be determined directly (Plagenhoef, 1973:166), an alternate technique is needed to calculate this parameter. The method used in this study was that proposed by Miller and Nelson (1973) whereby the radii of gyration are calculated from the moments of inertia determined from cadaver studies. Miller and Nelson (1973:98) quoted Fischer when they stated that the radius of gyration for the greater extremities with respect to all axes passing through the mass center and perpendicular to the long axis of the limb was three tenths of the segment length. The formula for calculation of the segment moments of inertia then became:

$$Ig=M*K**2=M(.3*L)**2$$

where

Ig=Moment of Inertia of the segment about G

M=Mass of Segment

K=Radius of Gyration

L=Length of the Segment

G=Mass Center

The moments of inertia around G (the mass center) of the segments are reported in Table I. These are comparable to those reported by Widule(1976), although they are larger due to the larger size of these subjects. The measures calculated by Widule were derived from the data of eight cadavers, all of which were much below normal size and weight. Plagenhoef(1971) also calculated the moments of inertia of the segments around axes passing through the proximal and distal ends of the particular segments--these were calculated from Dempster's data (1955) on cadaver moments of inertia. However, Miller and Nelson (1973:99) have noted that although these methods can provide estimates of masses and moments of inertia, they will always be somewhat inaccurate because they were derived from adult male cadavers. These inaccuracies may be magnified when the populations differ in age, sex, race, etc. However, since these estimates were the best available, these were used in the calculation of subsequent kinetic parameters in the present study.

TABLE I. Subject-Data-for-Kinetic-Analysis

	Upper Arm Segment			
Subject	DS	BL	SW	CM
Total Mass (kg.)	106.6	74.84	72.57	89.36
Segment Mass (% Total Body)*	3.3	3.0	3.0	3.3
Segment Mass (kg.)	3.52	2.24	2.18	2.95
Segment Weight (W=M*G) (Newtons)	34.54	21.98	21.39	28.95
Segment Length (cm.)	.39	.33	.31	34.5
Distance to C of G (43.6% from Prox end)	.170	.144	.135	.150
Moment of Inertia (around G, where I=M*K**2 and K=.3*L)	.0482	.0219	.0188	.0316
Moment of Inertia (around proximal end, where I=I(cg) + M*D**2)	.1499	.0683	.0585	.0979

	Lower Arm Segment			
Segment Mass (% Total Body)	1.9	1.6	1.6	1.9
Segment Mass (kg.)	2.02	1.197	1.16	1.69
Segment Weight (W=M*G) (Newtons)	19.82	11.75	11.38	16.58
Segment Length (cm.)	.29	.28	.27	29.5
Distance to C of G (43.0% from Prox end)	.125	.120	.116	.127
Moment of Inertia (around G, where I=M*K**2 and K=.3*L) (units:kg/m**2)	.0152	.0084	.0076	.0132
Moment of Inertia (around proximal end, where I=I(cg) + M*D**2)	.0467	.0256	0232	.0404

TABLE I. Subject-Data-for-Kinetic-Analysis-(cont'd)

Hand and Ball Segment				
	(Ball Mass=.185kg.)			
Segment Mass (% Total Body)	.65	.50	.50	.878
Segment Mass (kg.)	.878	.559	.549	.765
Segment Weight (W=M*G) (Newtons)	8.62	5.49	5.39	7.51
Segment Length (Actual Segment Length in cm.)	20.5	18.5	19.0	19.5
Distance to C of G (28.0% from Prox end)	.057	.0518	.053	.055
Moment of Inertia (around G, where I=M*K**2 and K=.3*L) (units:kg/m**2)	.00332	.00172	.00178	.00261
Moment of Inertia (around proximal end, where I=I(cg) + M*D**2)	.00617	.00322	.00332	.00492

Ground Reaction Forces

To calculate the ground reaction forces, the whole body of the subject was considered to be a single rigid body with the mass concentrated at the mass center. The position of the mass center was calculated by: digitizing the segmental endpoints for each of the body segments, calculating the mass center of each of the segments, and utilizing the segmental method of determination of the body mass center. The actual calculations were carried out by a computer program written expressly for the purpose of calculating and graphing the mass center. For the top two pitchers, the position of the mass center in each frame analyzed was determined by use of this mass center program (Bates,1974). The displacements between sucessive frames in the X and Y directions could then be calculated, and from this displacement data the velocities and accelerations of the mass center throughout the pitch could be determined. These kinematic parameters were calculated by use of a program written by the author, in which the raw displacement values were read in to the IMSL cubic spline smoothing program. These displacement values were then smoothed and the acceleration values were calculated. Using the principle of Newton's second law, the applied forces are equal to the mass times the acceleration of that mass, so that the horizontal and vertical ground reaction forces could be calculated from the accelerations of the mass center. The equations used in this calculation are found in Appendix C.

As well as the calculated ground reaction forces, the applied ground reaction forces were recorded by the force platform connected to the Honeywell visicorder. These forces were represented by a paper tape tracing of the forces exerted on the force platform in the X and Y direction. These two independent methods of determination of ground forces were compared qualititively by visual inspection. It was not possible to quantify accurately the magnitudes of the forces measured from the force plate, since these tracings were not accurately calibrated. This technique provided an estimate of the accuracy of the data calculated from the film coordinates and especially provided a check on the vertical and horizontal accelerations of the mass center, which are often subject to considerable error.

Angular Kinematics

The angular motions of the pitching arm were analyzed from the beginning of the delivery, to a point 5 frames (.10 sec) after release. To ensure a constant point of analysis for each of the eight pitches analyzed, the release frame was assumed to be zero, and the film was reversed to a position 40 frames prior to release. From this point in the delivery, the four segmental endpoints of the arm were digitized for every second frame through release of the ball and for five frames afterward. Because the frame rate was calculated to be exactly 100 fps, this represented a time interval of .02s between frames analyzed. A computer program was written for the HP 9825 which accepted as input the digitized segmental endpoints, and calculated the angular positions (segmental inclinations) for each of the three segments of the arm, for each of the 25 positions analyzed. All positions calculated were measured from the right horizontal in degrees, and each position in degrees was changed to radians within the computer program.

Since the greatest rise in the velocity of the upper arm segment occurs just after the high point of the backswing is reached, the pitching arm was analyzed in detail from this point. The four segmental endpoints of the arm were then digitized a second time, such that the film was reversed to a position 20 frames prior to release. From this point, every frame was digitized through release and for five frames afterward, for a total of 25 frames digitized at this shorter time interval between frames.

These angular positions for each of the three segments were then read into the Ahmdal 460V/6 computer, in which the cubic spline data smoothing programs were stored. These angular displacements were then smoothed by the IMSL cubic spline program called ICSSCU, which smooths the angluar displacement data to reduce the effects of random errors in the data. This cubic spline program has been used extensively in biomechanics research, and is the program recommended for data of this type (Mclaughlin et al., 1977; Zernicke et al., 1975). From this smoothed displacement data, the angular velocities and accelerations were calculated for each of the segments for each of the frames analyzed. The computer program written by the author to analyze these angular motions is reported in Appendix E. The angular displacement, velocity, and acceleration data was then graphed for each of the pitches analyzed . The angular displacements for each of the segments were plotted on the same graph against time so that these angular kinematic parameters could be compared, and this was also done for the angular velocity and acceleration values.

Linear Kinematics

The exact frame rate was determined by counting the number of frames between the flashes of the timing light on the edge of the film. The conversion factor for changing film distances into real life distances was calculated by use of a reference marker of known length in the field. From the coordinates of the upper limb joints and segmental centers of gravity, kinematic parameters were calculated for each of these points.

The linear kinematics of the pitching arm were calculated from the film data digitized separately of the 4 segmental endpoints of the arm, and from the angular displacement calculations. The shoulder joint displacements were smoothed using the cubic spline program described earlier, and the shoulder linear velocities and accelerations were calculated from this data.

The same computer program which was used to calculate the angular kinematics was expanded to carry out the linear kinematic calculations. The linear velocities and accelerations of the shoulder, elbow, wrist and fingertips were determined for each of the 25 frames analyzed, for each of the pitches. The kinematic analysis of each of the segments of the arm was carried out using the method described by Youm(1977a,1977b) and Pearson(1963). This method consisted of using vector equations to solve for the linear velocities and accelerations, once the angular kinematic parameters have been calculated. These equations have been reported by Youm (1977a,1977b). The relative velocity of a point at the end of a rotating segment is equal to the vector product of the angular velocity of the segment and the position vector of the segment, or, V = w x r where V = the linear velocity of the point, r = the position vector relative to the fixed endpoint of the segment, and w = the angular velocity of the segment. The absolute linear velocity of a point is equal to the vector sum of the absolute velocity of the proximal endpoint and the calculated relative linear velocity. For example, the velocity of the elbow joint is calculated as the vector sum of the velocity of the shoulder joint, and the cross product of the angular velocity of the upper arm segment and the vectors describing its' axis. Similarly, the acceleration of the shoulder joint is calculated as the vector sum of the tangential acceleration (the vector product of the angular acceleration of the segment and it's position vector), and the normal acceleration (the cross product of the angular velocity and the cross product of the position vector and the angular velocity of the segment)(w x (w x r)). A diagram of the segments and these formulas may be found in Appendix C.

Single Plane Kinetics

The kinetic segmental linear and angular accelerations and the mass parameter estimates of the body segments were incorporated into kinetic equations of motion for a mathematical model of the arm, as described by Zernicke(1977). The arm was modelled as a three-link rigid body system consisting of the upper arm segment, the lower arm segment, and the hand and ball segment. A free body diagram of these segments are reported in appendix D. The segments were assumed to be connected by hinge joints and friction at the joints was assumed to be negligible (Jensen, 1974). The forces and moments of force at each joint were calculated from the equations of Newtonian rigid-body dynamics. The general equations of motion consisted of two force equations; Fx=M*Accx and Fy=M*Accy, and one Moment of force equation; M=Iz*Alphaz (Meriam,1975:240). For each rigid body, the sum of the forces, either horizontal (Fx) or vertical (Fy), was equivalent to the product of the segment mass(m) and the corresponding horizontal or vertical acceleration of the mass center of that segment. Similarly, the sum of the moments of force (Mz) perpendicular to the plane of the motion was equal to the product of the segment's angular acceleration and the appropriate mass moment of inertia at the segment's center of mass (Zernicke, 1977:180).

Equations were developed to determine the magnitudes of the moments of force at the three joints of the upper extremity. These equations were modelled after those of Dillman(1970) in which the muscle forces acting on each of the segments to provide movement at the joints were replaced by an equivalent force at the joint and a couple causing rotation at the joint. These free body diagrams and equations were reported by Miller and Nelson (1973). It was therefore possible to determine the resultant joint torques at each joint, and to estimate their magnitudes and directions. The diagrams and equations used in the present study to calculate these kinetic parameters are reported in Appendix E. These joint torques are believed by many biomechanics researchers (Ariel,1974; Plagenhoef, 1971) to be an indication of the most important muscle group acting at a particular instant in the performance of a skill. Dillman(1970) has conducted an extensive study of the magnitudes of these joint torques and their effects on movements during a performance.

Three Dimensional Analysis

To determine the locations of the points of interest of the throwing arm in three-space, it was necessary to digitize these points for the sixty frames of interest from the film from both of the cameras. The film was analyzed frame-by-frame, so that for each frame twenty two points were digitized using the HP digitizing board. These points included the segmental endpoints of each of the body segments, as well as a reference point in each frame, and the center of the ball. These points were read into the HP 9825 calculator, and stored on HP cassette tapes one frame at a time. This procedure was carried out for one complete pitch for each of the four subjects. Since one complete pitch normally occurred in sixty frames, and the pitch was filmed from two cameras, each pitch required one-hundred and twenty frames of digitized data. This data stored on cassette tapes was then read into the Ahmdal 460V/6 computer by means of the interface with the HP 9825 and the accompanying programs described earlier.

The single most critical problem to be solved in this analysis was that of the synchronization of the film frames of each pitch. Although the cameras were both started at the same time, and the frame rate was the same for each camera, the film was in a slightly different position in the camera for each pitch. This caused the film data to be slightly out of phase, and so produced some inaccuracies in the spatial coordinates. However, the films were synchronized by a frame-by-frame analysis by the author, in which the frames occurring at the same time (ie. containing a light flash from the timer), were marked with a marking pen. During the digitizing process, these frames were carefully synchronized by numbering them consecutively for storage.

Since the three-dimensional analysis program was based on the accuracy of the digitized data, it was then necessary to correct each of the digitized points for a common reference point. A Fortran program was written by the author to perform these corrections on each of the data points. The digitized points from each of the cameras were then read in to a three dimensional analysis program written by Van Gheluwe(1977), which was subsequently adapted by the author to run on the University of Alberta computer system. This program accepted as input the digitized points from each of the cameras, and from these points the spatial coordinates of each of these points are calculated. The program was based on the determination of the location of each of the cameras in space by their positions in relation to the 'tree', or set of orthogonal axes described earlier. This tree was filmed by each of the cameras for each of the subjects, and twenty-two points were digitized from the tree from each of the camera views. For a detailed description of this program, see Appendix B.

Using this program, then, the spatial coordinates of the four segmental endpoints of the pitching arm, as well as the center of the ball, were determined. Each of these points then had a set of X,Y, and Z values for each of the frames digitized. From these X,Y, and Z values it was then possible to calculate the displacement, velocity, and acceleration values in each of these three directions . A computer program was written by the author to calculate these smoothed values using the IMSL cubic spline routine. The calculated linear velocity values for each of the X,Y, and Z directions were then graphed against time, and compared to the previously calculated X and Y values. The graph of the Z velocity values were of particular interest to determine the relative magnitude of these in comparison to those in the X-Y plane.

Three Dimensional Angular Velocities

The angular motions of interest in this section of the analysis were primarily those motions occurring around the longitudinal axes of the arm segments. No previous studies were located in which these rotations were estimated by vector analysis methods in a vigorous, high speed activity. Gowitzke and Waddell(1977) attempted to determine the magnitudes of forearm and upper arm rotations in the badminton overhead clear by measuring the displacement of a tape strip filmed on the arm segments. However, this method is open to question because of the assumptions made that the movement of the tape marker is like the movement on the arc of a circle. Also the radius of the circle(the arm segment) may only be roughly estimated.

The present analysis was carried out on the lower arm segment motions during the pitch of two of the subjects. In order to calculate the magnitude of the angular velocity of this segment in relation to the major reference system, it was necessary to determine the X,Y, and Z coordinates of three non-collinear points on this segment through the desired range of movement. These points were designated as: the joint marker on the lateral aspect of the elbow joint, and the joint markers on the medial and the lateral sides of the wrist joints. These three points on the lower arm segment, as well as the shoulder joint and the tip of the third finger were digitized for each subject for the eight frames during release of the ball, from each of the two cameras. These five points from each of the films were then input into the three-dimensional analysis program, and the X,Y, and Z coordinates of each of the points were then determined.

Since the positions of each of these points over this eight frames was now available, the displacements, velocities and accelerations of each of the points were then calculated. These calculations were carried out by a computer program written by the author, in which each of the X,Y and Z coordinates were read into the IMSL smoothing program and the required velocities were produced as output. These linear velocities were then further utilized to calculate the magnitude of the total angular velocity of this segment in relation to the original X,Y, and Z axes. The equations used to determine these parameters are reported in Appendix D.

In order to calculate the angular velocities of the lower arm segment around a set of axes passing through the actual segment, it was then necessary to define this set of axes. The position vectors defining this set of axes were determined by use of the spatial coordinates of the other segmental endpoints digitized in this analysis (Appendix D.). Since the total angular velocity components were determined, and the position vectors were then defined, it was then possible to define three equations in three unknowns for the scalar product of these components. The solutions for these three equations contained the three angular velocity components for the lower arm segment (Appendix D). A computer program was written by the author in which the above calculations were carried out from the X,Y, and Z input data. The output consisted of the solutions to the three equations, which were the angular velocity estimates. Although in the present study the calculations were carried out for only one of the arm segments, this method made it possible to determine the magnitudes of these rotations for any of the body segments.

CHAPTER IV

Results and Discussion

The results of the analysis of the windmill pitch in softball are subdivided into the following general topics:

1. Introduction to Analysis of Results
2. Individual Subject Data
3. Description of the Pitching Motion
4. Ball Velocities
5. Ground Reaction Forces
6. Angular Kinematics
7. Linear Kinematics
8. Linear and Angular Kinetics
9. Three Dimensional Analysis
10. Three Dimensional Angular Velocities

Introduction to Analysis of Results

The analysis of human performance from a quantitative, mechanical point of view is subject to certain inaccuracies due to unavoidable assumptions in the modelling of the movement. The body is assumed to be an assemblage of rigid segments, which is obviously not the case since these segements are constantly changing due to tissue deformations, blood movement, and changing concentrations of substances in the tissues. The joints are assumed to be simple pinned joints which allow movement in only one plane, when in fact there are movements occurring in all three planes in the joints of the upper extremity. The masses and moments of inertia of the body segments are estimated from other studies, in which these measurements are determined from cadaver data, or from averages determined from a large number of subjects. Movement techniques are very individual, and depend on such characteristics of the performer as speed, strength, body build, and temperament. Therefore, any attempt to describe the characteristics of a movement in quantitative terms is subject to a certain amount of error. However, studies of this type will help us to a greater understanding of the kinetic and kinematic parameters involved in skilled performance, and in that way provide greater insight to teachers and coaches of these skills.

Although many experimenters are engaged in the applications of classical mechanics to human movement, the many estimated parameters make these studies inaccurate in many cases (Ayoub,1974). It is often not possible to explain all the quantitative numerical results on the basis of efficient mechanics. Nubar and Contini(1961) have postulated what they have called the 'minimal principle', such that only as much muscle force as is necessary to provide for the efficient movement of the body part is applied. However, this theory has not been verified by the results of studies which have examined the magnitudes of such forces at the joints.

Individual Subject Data

The anthropometric and personal data of each of the subjects is summarized in Table II. There was a wide range of ages in the four subjects tested, from the youngest female at 19 years, to the oldest male at 38 years. It is notable that these two subjects at the extremes of age were judged to be the two most highly skilled of the pitchers tested. It is also notable that many of the anthropometric

TABLE II.-INDIVIDUAL-SUBJECT-DATA

SUBJECT	DS	BL	SW	CM
SEX	MALE	FEMALE	FEMALE	MALE
PARAMETER				
AGE	38	32	19	23
HEIGHT (CM.)	193.0	177.8	175.3	185.4
WEIGHT (KG.)	106.6	74.84	72.57	89.36
UPPER ARM LENGTH (CM.)	38.	33.	31.	34.5
BICEPS DIAMETER (CM.) (RELAXED)	37.	28.	29.5	35.
(FLEXED)	40.	29.5	32.	38.5
LOWER ARM LENGTH (CM.)	29.	28.	27.	29.5
WRIST DIAMETER (CM.)	21.	16.5	16.	18.5
HAND LENGTH (CM.)	20.5	18.5	19.	19.5
HAND SPAN (CM.)	26.	20.	19.	23.

measures are much larger than those for the average person, as reported in the tables of the most recent anthropometric data available. (Diffrient,1974) The average height for a large-framed male was estimated (from the tables) to be 188 cm, while Subject DS was 193.0 cm tall. The average height reported for a large-framed female was 174 cm, while Subject BL was 177.8 cm tall. The average weight for a large male was estimated at 87.1 kg, while Subject DS weighed 106.6 kg; the female tested was also considerably heavier than the normal for a large person. Since all of the subjects tested were above the 90th percentile in terms of their height and weight compared to the average person, this may indicate that a prerequisite for successful pitching in the game of softball is size.

The individual anthropometric measurements of the upper extremity of the subjects were also well above the average measures published as being those of a large person (Table II). For example, the upper arm length of a large male was estimated at 30.2 cm (Diffrient,1974), while the present Subject DS had a measured upper arm length of 38 cm. Similarly, the average flexed biceps diameter for a large male was reported to be 35.8 cm, while that of DS was measured to be 40.0 cm. The largest subject in the present study was found to be up to 25 per cent larger than the largest subject reported in current literature, and this difference was apparent in both the male and female subjects. These results possibly suggest that highly skilled softball pitchers are generally much larger than the average person, and that in order to be a successful pitcher the individual should posess this exceptional size.

The subjects chosen for the present study were the most highly skilled available to the investigator at the time of the study, and the summaries of their softball experiences will verify this conclusion. The summaries are included in Appendix D, page . All subjects had had at least some national exposure, being involved in some level of National Championships. The most highly skilled male subject had led his team to the Western Canadian Men's Fastball League Championship last year(1977). The most highly skilled female had led the Alberta Provincial Team to a third-place finish at the Canada Summer Games in Newfoundland in 1977. Although the other two pitchers were not actively involved in 'A' level softball in the past year, both had some experience at this level in their careers.

Description of the Pitching Motion

The film of the four highly skilled subjects was viewed numerous times by the present investigator, and the following description represents the skill as it was performed by at least three of the subjects. Sequence Photographs taken directly from the film of subjects 1 and 2 are found in Figures 1 and 2. The total motion of the windmill pitch takes only .4 to .5 second to perform, from the presentation position which signals the start of the pitch, to the time the ball actually leaves the hand of the pitcher. The temporal characteristics of the softball pitch are reported in Table III. The time reported for each pitch was taken as the time from the end of the presentation phase of the pitch to the point at which the ball is released. It should be noted that this time was affected by extraneous motions of the pitcher following separation of the hands. For example, Subject BL moved her pitching arm backward after separation, and this motion accounted for the longer period of time taken by this subject in the actual delivery of the ball. Otherwise, the average time taken for the pitcher to deliver the ball to the batter was between .50 and .60 seconds, which was a relatively short time to impart such a large velocity to the ball. The time taken for the actual downswing of the pitching arm prior to delivery was

Table III Stride Length and Temporal Characteristics of Pitchers

Subject	DS	BL	SW	CM
Average Stride Length (Metres)	1.019	1.102	1.196	1.50
% of Height	52.79	61.97	68.22	80.90
Time for Complete Pitch (Sec)	.55	.69	.56	.60
Time to Top of Backswing (S)	.40	.52	.41	.45
Time from Top of BS to Release (S)	.15	.16	.15	.15

approximately .15 seconds, which indicates that the majority of the forceful muscle activity of the pitching arm occurs in this short time period.

The presentation position is one in which the pitcher must stand motionless with both feet in contact with the pitcher's board, with the ball held with both hands in front of the pitcher. This position must be held for at least two seconds prior to the beginning of the pitch, according to the Official Rules(1978:13). This position is illustrated in Figures 1A and 2A. From this position, two movements occur simultaneously: the hands separate and the arm is flexed at the shoulder to raise the ball in line with a position approximately opposite the midline of the trunk. At the same time, the left leg is raised and the pitcher commences to step forward onto this foot. Thus these two movements are occurring simultaneously, and in a coordinated pattern as is seen in taking a normal walking step forward--the right hip and the left shoulder are both flexing and raising their respective limbs upward and forward from their starting positions. This pattern is also notable in that the angular displacement of each of these limbs is occurring at the same rate, so that their respective angular velocities are similar for the first part of the movement. The coordinated pattern of movement such as this one described for these highly skilled performers serve to illustrate the many factors which comprise a high level performance. These movements are illustrated in Figures 1A-G,2A-G. This pattern is likely facilitated by the action of the crossed extensor reflex, in which the movement in one limb is accompanied by increased tonus in the muscles of the contralateral limb. Thus in this case the extensor muscles of the right lower extremity are facilitated by increased tonus, along with the extensors of the left upper extremity. In the contralateral limbs, the extensor tone is inhibited, and thus flexor tone is facilitated.

As the right arm and the left leg are moving upward and forward during this phase of the delivery, the right hip, knee and ankle are being rapidly and forcefully extended to drive the body forward onto the left foot. Since it is commonly accepted that one of the characterisitcs of a highly skilled pitcher is an extremely long step into the pitch, it was expected that the present performers all used such a step. The measurements of the length of the stride into the pitch are reported in Table III, first as an absolute length and then as a percentage of the subject's height. An earlier study of a highly skilled softball pitcher (Zollinger,1973) reported that the average stride length was 68 per cent of the performer's height, which was very close to the findings in the present study. Subject SW had a stride length of almost exactly that of the skilled pitcher in the above study, while BL and DS had one somewhat shorter. Subject CM had an exceptionally long stride length, but this was due to the long hop which he took on his right foot prior to placing his left foot on the ground. As was stated earlier, although this method may have some advantage in imparting greater forces to the ball, it is illegal according to the rules of the game, and would likely be called as an illegal pitch in a game. The rule states clearly that "The pivot foor must remain in contact with the pitcher's plate until the other foot with which the pitcher steps toward home plate has touched the ground (CASA,1968:13)."

Another important motion occurring during this step is the rotation of the trunk laterally toward the side of the pitching arm. As the pitching arm is being raised forward and upward, the trunk is rotating to the right, so that the shoulder movement which was originally flexion, becomes abduction as the trunk twists (See Figure 1H-I,2H-I). As the pitching arm reaches a position directly above the shoulder, the left foot contacts the ground as the step forward is completed (See Figure 1H,2H). It is notable that the pitching arm remains relatively straight during this part of the motion, maintaining an angle at the elbow joint of approximately 170 degrees. The wrist joint also actually maintains a relatively stable position throughout the windup, but it appears to be undergoing changes due to the rotation occurring in the upper arm and shoulder. When the left foot is firmly planted on the ground in a position directly in front of the pitcher, the body weight is shifted onto this foot (See Figure 1I-K,2I-K). The foot is planted so that the toe is pointing toward home plate, as this

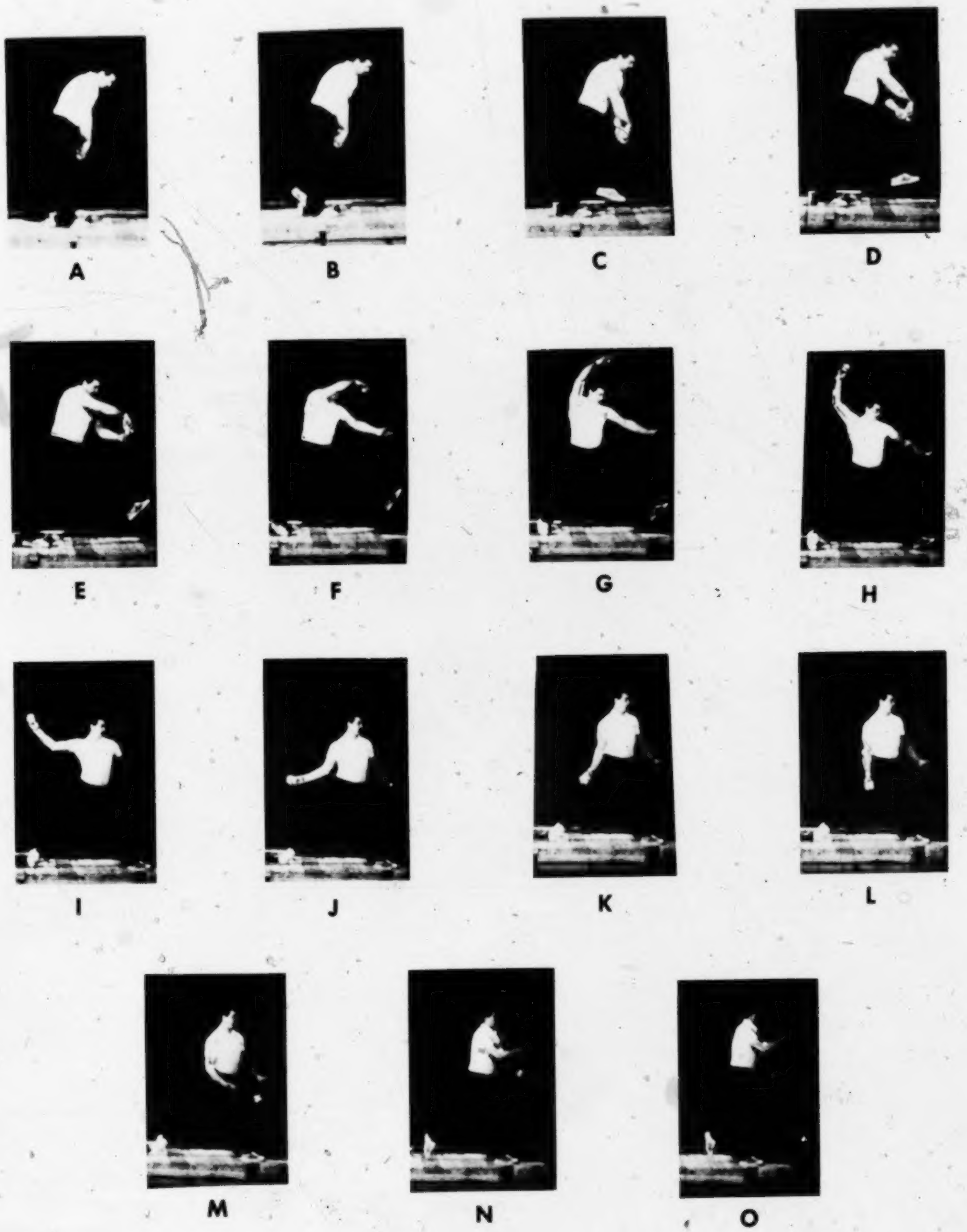

A
B
C
D
E
F
G
H
I
J
K
L
M
N
O

Figure 1. Sequence Photographs of Subject 1.

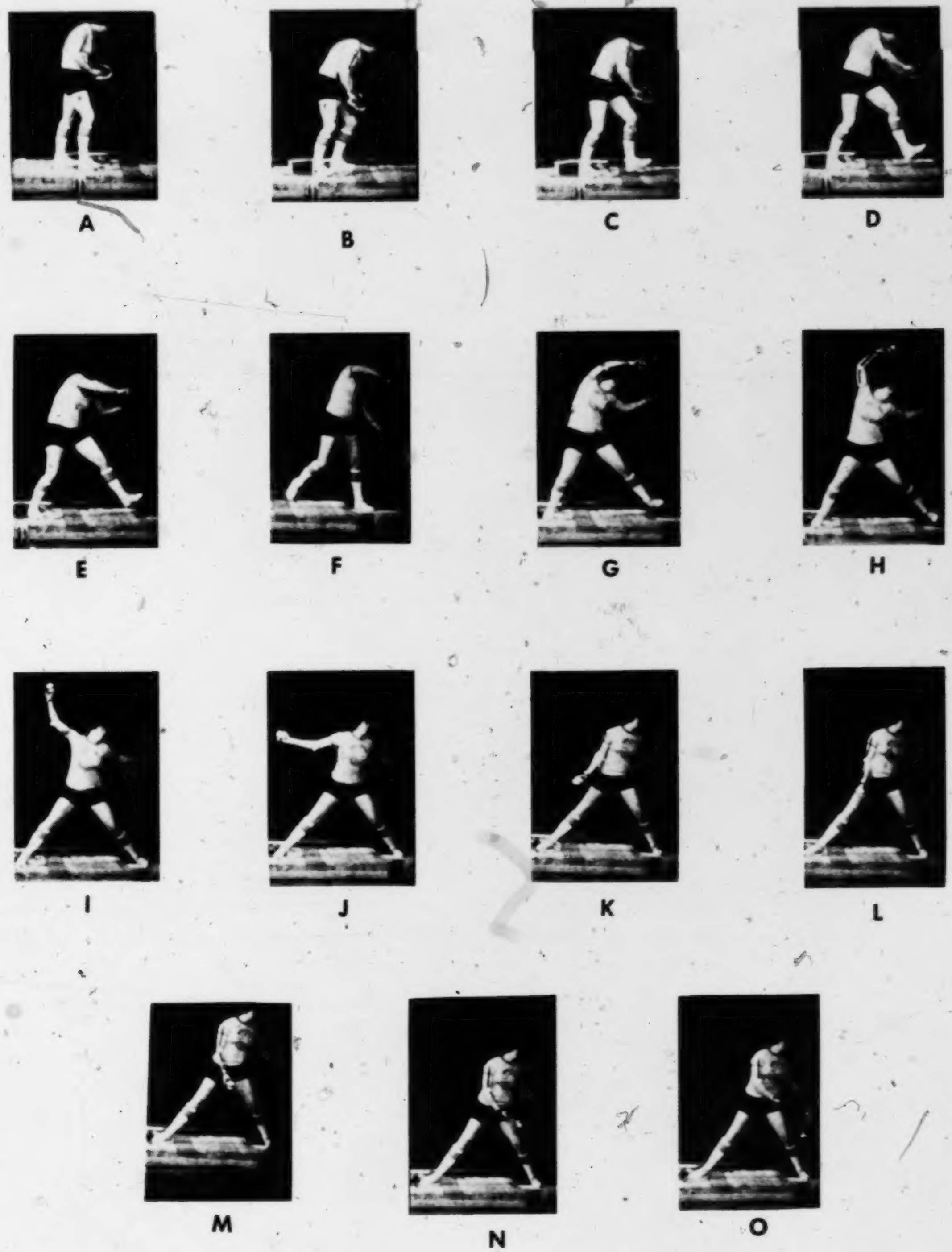

A
B
C
D
E
F
G
H
I
J
K
L
M
N
O

Figure 2. Sequence Photographs of Subject 2.

position of lateral rotation of the left hip allows for a full range of medial rotation of the trunk around this hip during delivery. Although three of the subjects in this study exhibited the above position of the left foot, one of the female performers placed this foot in a position at right angles to the direction of the pitch (See Figure 2I-K). It is notable that this position did in fact restrict the trunk rotation of this subject, who then exhibited little trunk rotation during delivery of the ball.

From this position with the arm directly overhead and the weight being taken on the left foot, the shoulder is now forcefully adducted and flexed to bring the ball around to the position of release. As the arm is moving forward and downward, the trunk is also undergoing rotation to the left-- this rotation consists of medial rotation of the left hip, as well as spinal rotation to the left. As the arm is moving downward, the distal segments are trailing the proximal segments--the upper arm segment is leading the motion, followed by the lower arm, and the hand-and-ball segment is trailing (See Figure 1I-J). This alignment is maintained up to .04 seconds before release, at which time the lower arm, and then the hand pass the upper arm segment (in terms of their angular positions from the right horizontal). The exact timing of the alignment of the arm segments during release will be described in a later section (See Figure J-L,2J-L).

Probably the most notable movement occurring in the upper limb during the softball pitch is the rotation of the forearm, accompanied by some rotation of the upper arm segment. The joint movement of importance consists of forceful and rapid pronation of the forearm, beginning at a point .03 seconds prior to release of the ball (See Figure 1J-L,2J-L). This movement is undoubtedly a major contributor to the final velocity of the ball, accompanied by wrist flexion which is likely the result of the rapid pronation movement rather than the concentric contraction of the wrist flexors. Zollinger (1973) has noted that "the wrist was fully flexed at the release", which was also observed in this study although this wrist flexion movement by itself may not be of major importance in contributing to the velocity of the ball.

The ball is released at a point approximately opposite to the midline of the body, or in a position just after the hand and ball pass the right leg (See Figure 1L,2M). At this point in the pitch, the weight shifted completely onto the left foot, and the back foot lost contact with the pitching rubber. It is notable that although the rules of softball state (CASA,1978:13) that the pitcher must remain in contact with the pitching rubber until the other foot with which the pitcher steps toward home plate has touched the ground, this rule is often broken in practice. Of the subjects filmed in the present study, three of the subjects managed to keep the back foot in contact with the force plate until the front foot touched the ground.. One of the subjects was consistently over one meter in front of the rubber at the time of release--this style of pitching would almost certainly be called as an illegal pitch by the umpire in a game situation.

The pitching arm continues to flex at the shoulder joint after release of the ball, so that the follow-through is completed with the hand in a position above the head (See Figure 10). Although the follow-through has no direct effect on the path of the ball after the ball has left the hand, a long follow-through is desirable to ensure that the pitching hand has not lost any velocity prior to release of the ball. Also, using a long range of movement through which to decelerate the segments of the pitching arm will ensure that the momentum of the arm is dissipated gradually to help prevent undue strain on the shoulder joint. The pitcher normally finishes in a position squarely facing the batter, with the feet parallel so that he is able to field any balls which may be hit directly back towards him.

The pitching motion of each of the subjects if further illustrated by computer-drawn plots of each of the body segments and the ball (See Figures 3,4). In the subsequent Figures, the subjects have been identified by number as follows: Subject 1-Dale Smith; Subject 2-Sue Wilcox; Subject 3-Bernice Lechner; Subject 4-Clint Marshall. This system of identification has been used throughout the remainder of the study. These plots were constructed from the digitized segmental endpoints of the best pitch of Subject 1 and

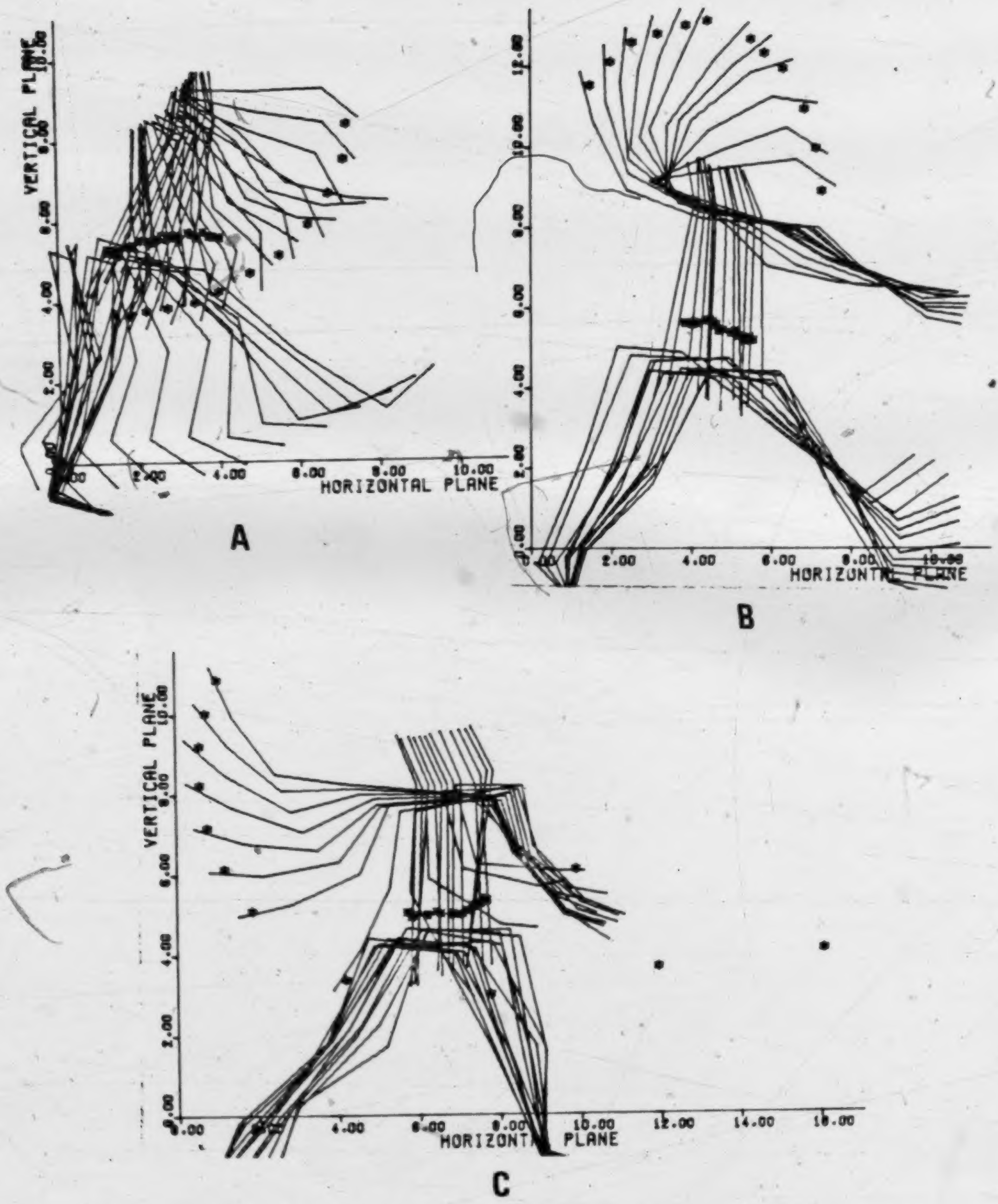


Figure 3. Pitching Motion of Subject 1.

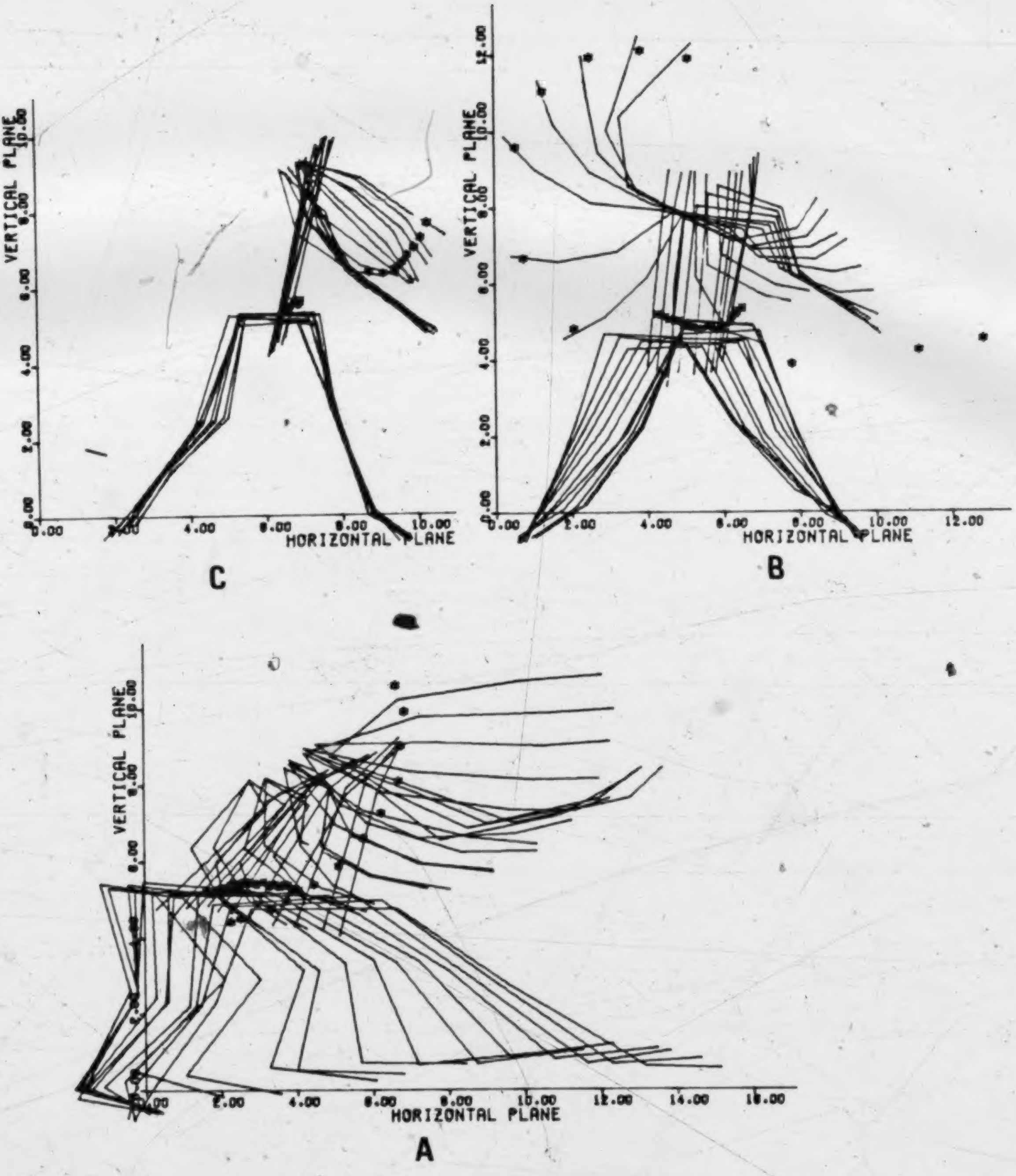


Figure 4. Pitching Motion of Subject 2.

Table IV Ball Velocities of Pitched Balls (Metres/Second)

Pitch# / Subject	1	2	3	4	5	Average
DS	30.43	29.53	29.78	28.87	31.30	29.68
BL	24.42	25.17	24.67	23.97	24.06	24.46
SW	24.71	24.95	25.41	24.95	24.70	24.94
CM	32.22	32.72	32.11	32.88	32.38	32.46

Subject 2, and in most cases every second frame was plotted. Thus these plots represent time intervals of .02 seconds between frames. One of the most important values of plots of this type is to illustrate the consistency of the digitized data. If the segmental endpoints were inaccurately or inconsistently digitized, the plots would be erratic and errors would be apparent. In the case of the two plots included here,no highly inaccurate points are visible on the plots.

Another illustration of interest in the softball pitch is that of the path of the segmental endpoints for the pitching arm of each of these subjects (See Figure 5,6). These figures once again serve to illustrate the consistency of the path of these endpoints for the highly skilled pitchers in this study. The consistency of the point of release for each of these subjects is also apparent from these figures (1C,2B). As was noted from the sequence photographs reported earlier, the pitching arm follows a circular pathway throughout the windup for this skill, with

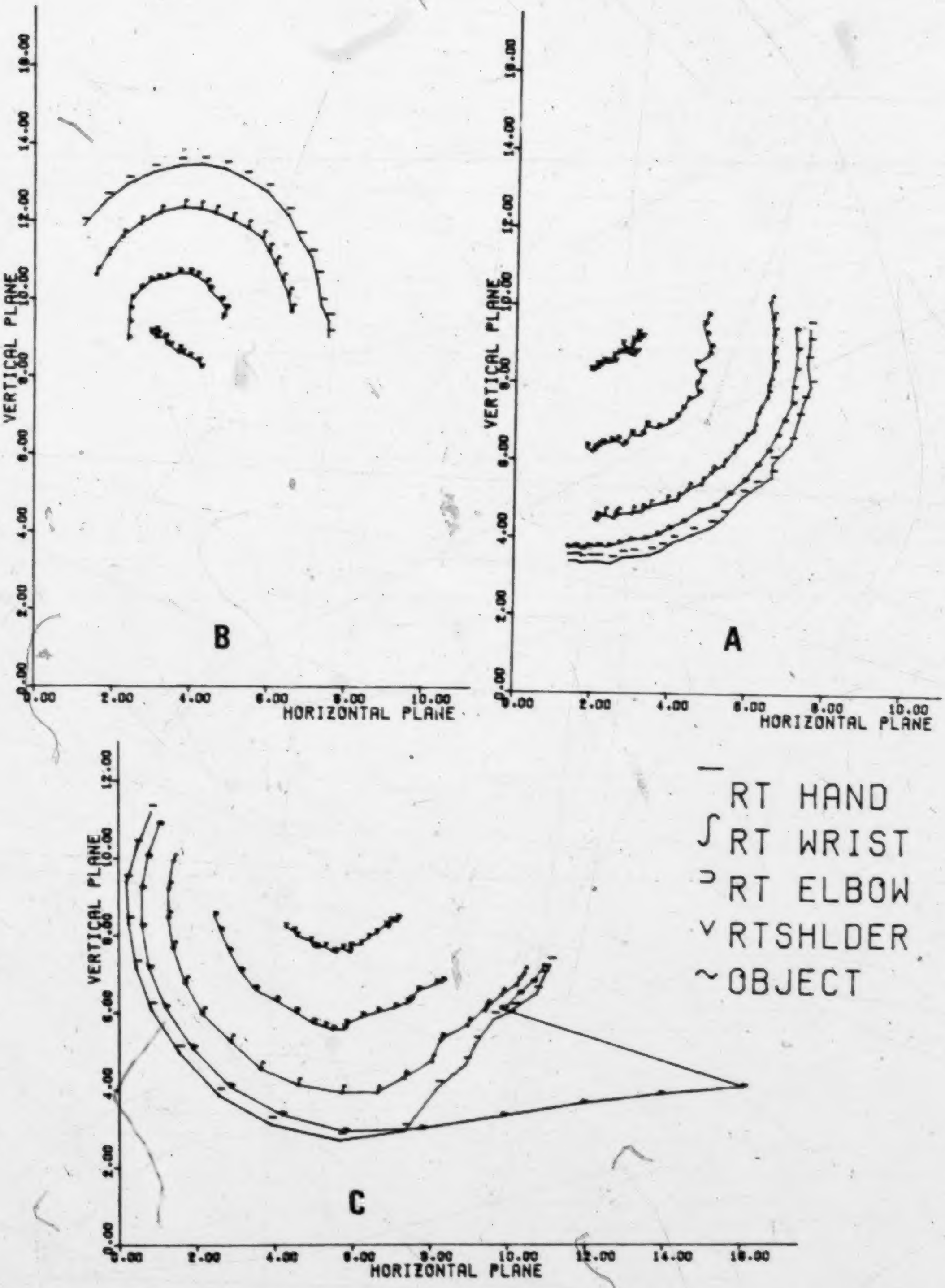


Figure 5. Path of Segmental Endpoints of Subject 1.

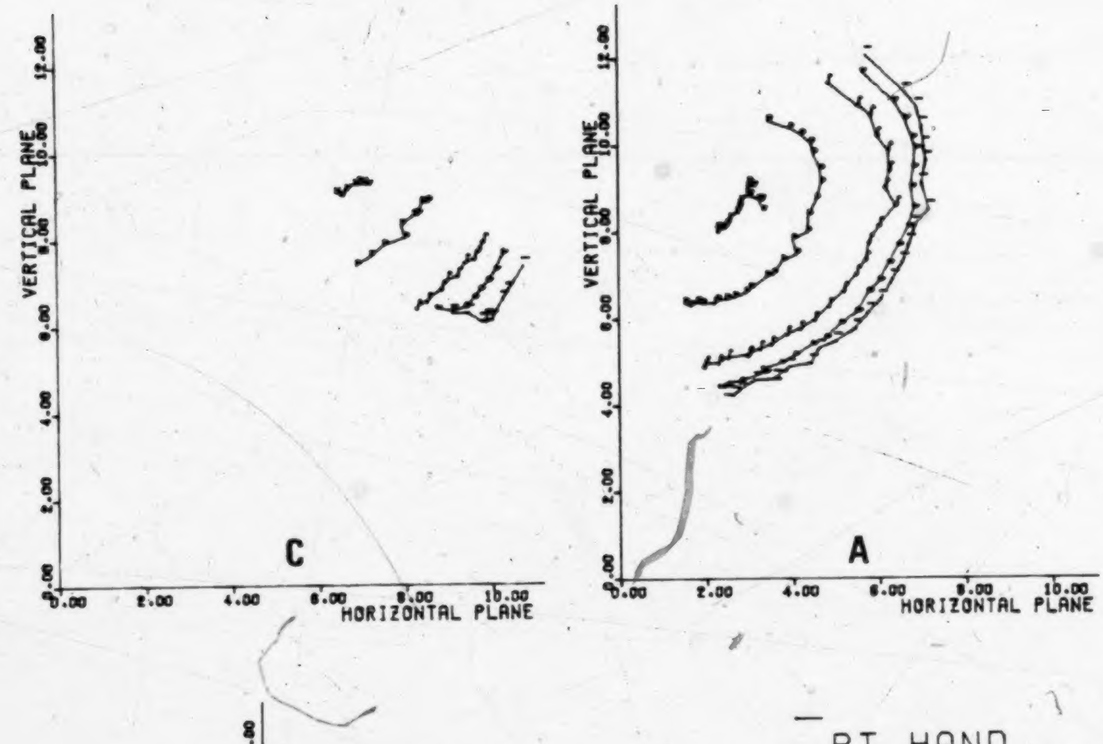


Figure 6. Path of Segmental Endpoints of Subject 2.

the velocity of the endpoint on the limb being maximal at release.

Ball Velocities

The velocities for the best five pitches of each of the four pitchers tested are reported in Table IV. Although the fastest measured velocities were produced by Subject CM, this subject was the one mentioned earlier as being at least one meter off the rubber at the time of release. One of the reasons for this illegal pitching style was that he started with his left foot a good distance behind his right foot on the pitching rubber. He was then able to take a very long step into the pitch, and his body had a very high horizontal velocity into the release. In addition, this subject used a technique known as the 'crow-hop', in which the right foot drives the body forcefully from the rubber, takes a short hop, and then lands again some distance from the rubber, and the pitching motion proceeds from this point. It is clear that this technique may have some advantage in that the velocity of the body is once again increased markedly, but it must be noted that it is illegal. It is for this reason that the pitches of this Subject were not chosen for the most detailed analysis, although if the criterion of maximum velocity were used strictly for the choice of the most effective pitches, his would be chosen.

The measured velocities of these skilled pitchers were seen to be very consistent between pitches, and relatively consistent between the male and the female performers. The pitches of DS were among those chosen for the most detailed analysis because these pitches were closest to a legal pitch in a game situation; as well as those of SW as these were the fastest of the female performers.

One further point regarding ball velocities during the pitch is the relationship between ball velocity and the velocity of the hand at release of the ball. For all of the pitches tested, the release velocity of the ball was found to be up to four or five meters per second faster than the velocity of the hand at release. This pattern has been noted earlier by Macmillan(1975) and Roberts and Metcalfe(1968), in studies of football kicking. Both these investigators found that the release velocity of the ball was considerably faster than the velocity of the foot at contact. Roberts and Metcalfe(1968:317) stated: "When contact is good the ball speed is 5 to 7 M/s faster than the foot". This pattern may be explained by the principle of transfer of momentum, whereby the mass times velocity of the hand and arm complex is so much greater than that of the ball's mass times velocity, that the release velocity of the ball after contact is greater than that of the hand. This does pose some interesting questions regarding the nature of the release of the ball by the pitcher, as it is possible that the efficiency of this release may be a factor in the efficiency of the transfer of momentum. More detailed analysis of this interaction is necessary before it is fully understood.

Ground Reaction Forces

The graphs of the calculated and the measured ground reaction forces are shown in Figures 7 and 8. Since the general shape of these curves is very similar, it may be concluded that the forces calculated from the mass center displacement data are reasonably accurate estimates of these forces. The force curves for Subject 1 (Figure 7) illustrate that the peak X force is exerted prior to the peak Y forces, and that there is in fact likely a summation effect of these two components of the ground reaction force. There is also a period of overlap of these two force curves seen in both of the representative curves, so that while the downward forces are decreasing in magnitude, the upward forces are increasing. This occurs during the windup at the time that the weight is being taken onto the front foot, and the body weight is actually moving downward onto this foot. At the same time the X forces are reaching their peak, as the pitcher is forcefully driving his body weight forward onto this left leg. The peak Y force is reached very close to the point of release of the ball, and is likely caused by a very forceful extension of the joints of the right leg as the subject drives his body upward and forward into the pitch. This forceful hip, knee and ankle extension is also accompanied by rapid and forceful rotation of the body

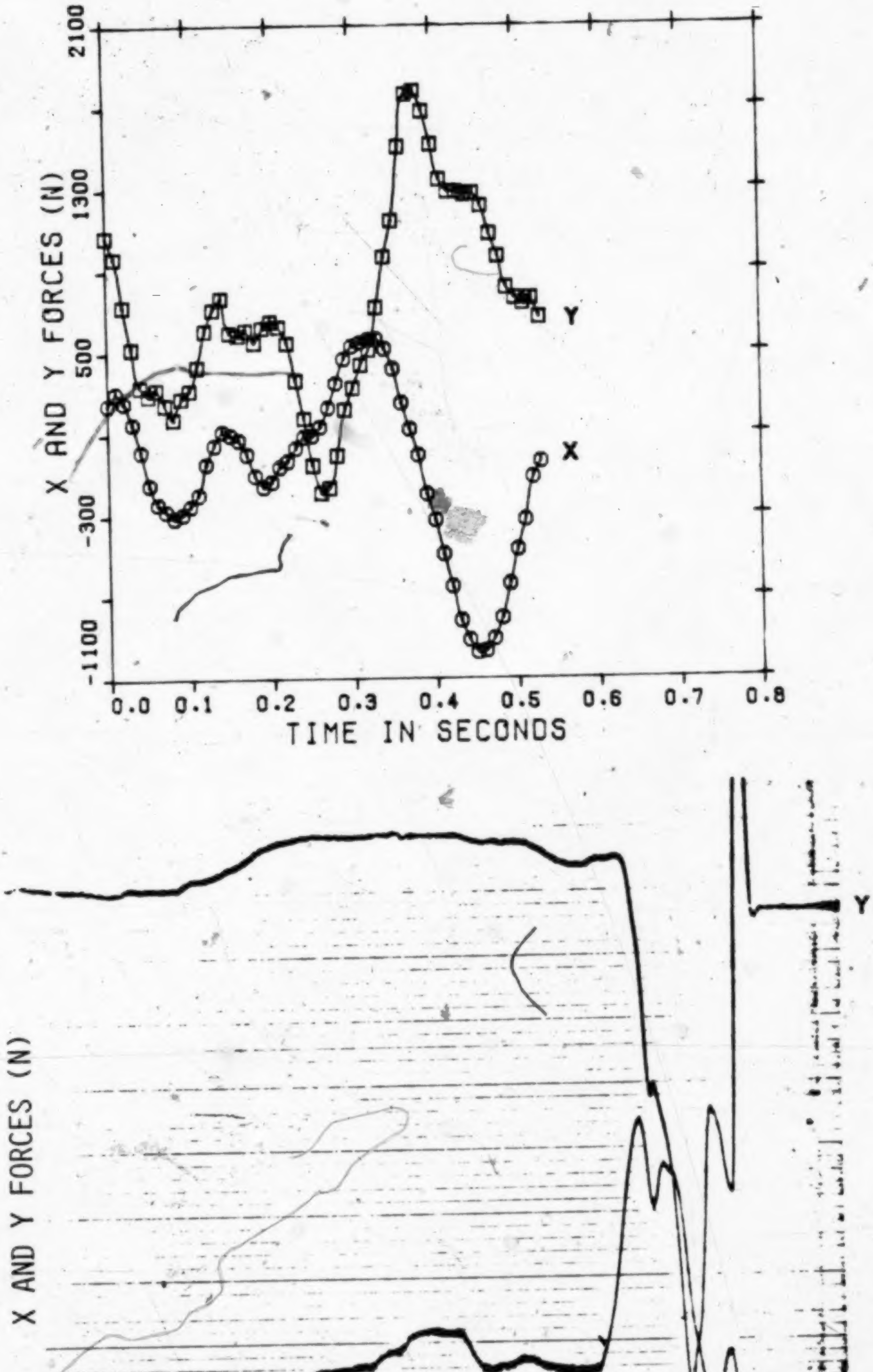


Figure 7. Ground Reaction Forces: Calculated and Force Platform Measures of Subject 1.

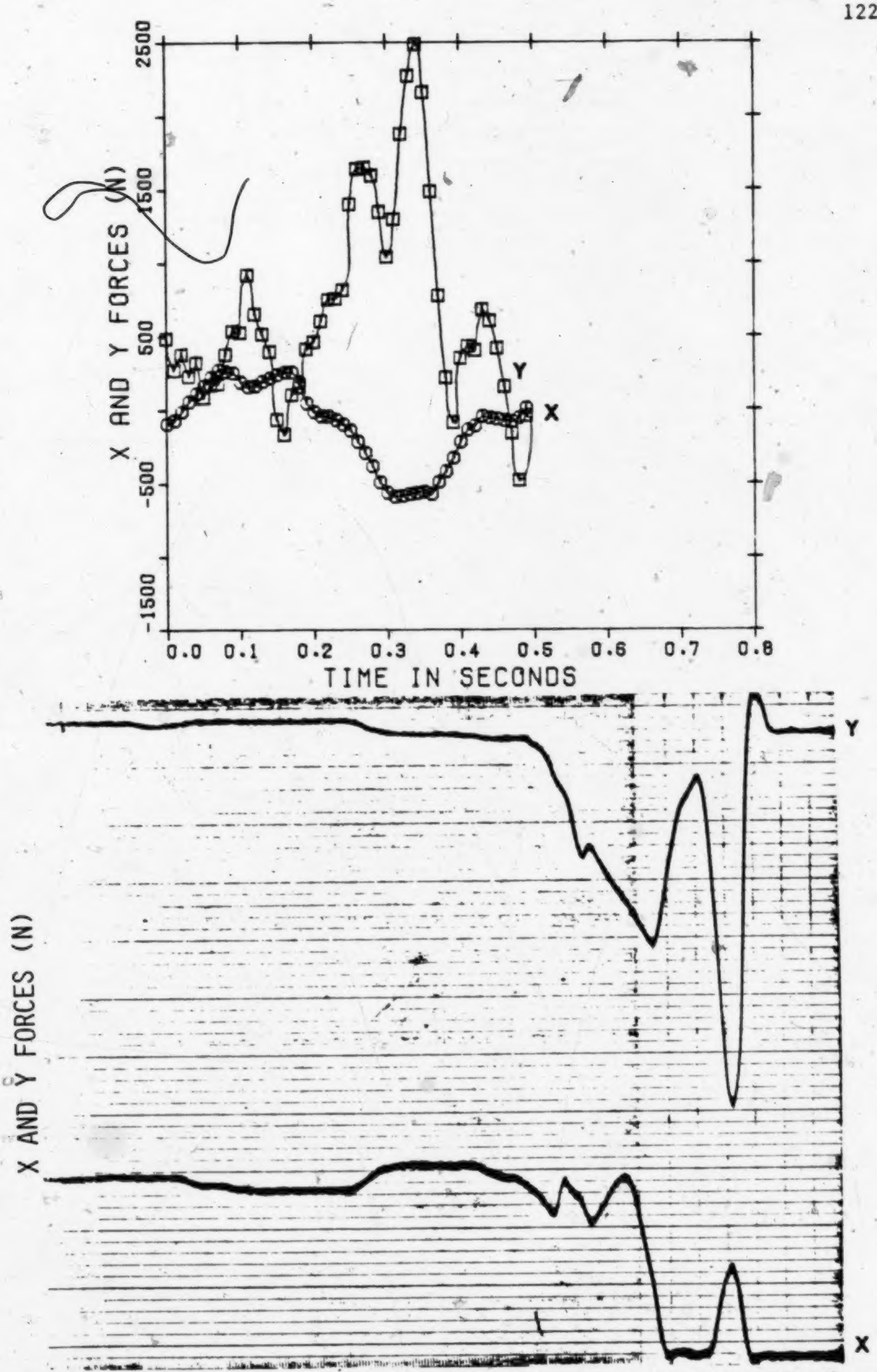


Figure 8. Ground Reaction Forces: Calculated and Force Platform Measures of Subject 2.

around the left hip (lateral body rotation). These rapid leg extension movements are accompanied by the rapid shoulder adduction and flexion--all of which produce downward forces which cause the peak at this point in the skill.

The force curves for Subject 2 are quite different from those produced for Subject 1, indicating that highly skilled performers may be exerting their body forces in quite different ways to produce a similar skilled performance (Figure 8). The peak X forces are reached much earlier in the skill for this subject, and in fact the X forces are being exerted in a negative direction at the time of release of the ball for this subject. The Y forces are somewhat similar to those exhibited by Subject 1, and in fact the peak of the Y ground reaction forces occurs at almost exactly the same instant in the delivery for each of the subjects. This point is approximately .04-.05 seconds prior to release of the ball.

Although this is a very noticeable peak, a recent study has indicated that a greater peak of ground reaction forces is not necessarily better. Kermond and Konz(1978) studied the force plate tracings of a highly skilled football kicker, and they found that the vertical force peak was significantly inversely related to the predicted kick distance. They stated: "This implies that a greater predicted distance is associated with a lesser ground force reaction. In practical terms, a kicker should try to maximize the force transfer to the ball and minimize the amount of pushing down on the ground with the support leg. It implies that the support leg ought to 'caress' the ground rather than 'stomp' on it (1978:76)". However, these authors attempted no real explanation for this phenomenon, and in fact there are few explanations to verify this conclusion. It would seem more likely that a greater vertical force component would produce a greater force against the ball. More study is needed to examine this question.

Angular Kinematics

Angular Displacements

The angular displacements of each of the arm segments against time are shown in Figures 9,16,23,30,37 and the numerical values of these measurements are reported in Appendix G, Raw Data Tables. The angular displacements have been determined by two independent sets of digitized data--the first set of displacements were digitized from the beginning of the windup (.40 secs) and every second frame was digitized through release and followthrough; and the second set of displacements was digitized from a point at the top of the backswing (.20 secs) and every frame was digitized through release and follow-through. The two sets of data for each pitch then included: a larger overview of the entire pitching motion, and a more detailed view of the frame-by-frame analysis of the motion of the segments through release. There were therefore two separate sets of

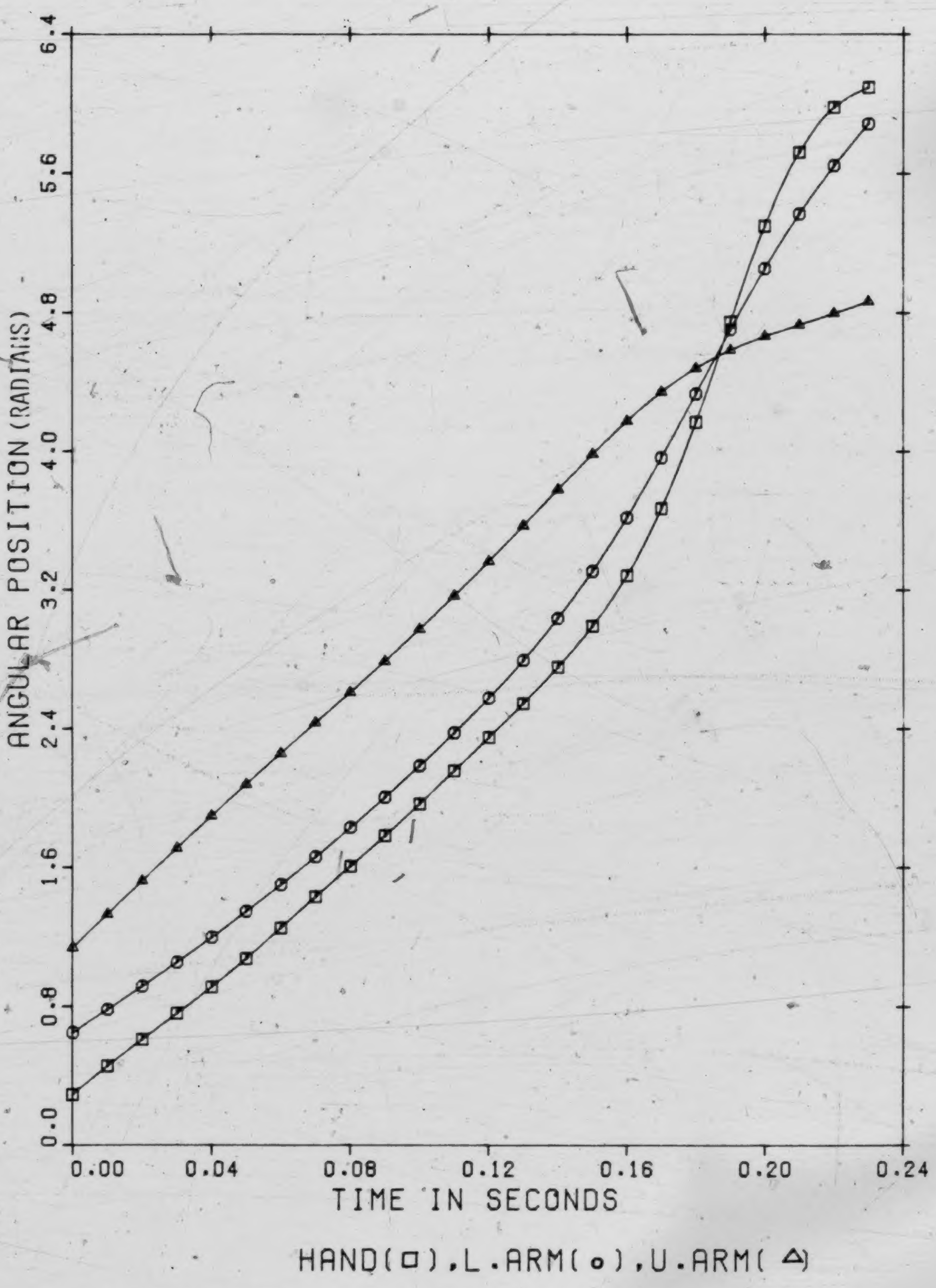


Figure 9. Angular Position vs Time of the Arm Segments for Subject 1.

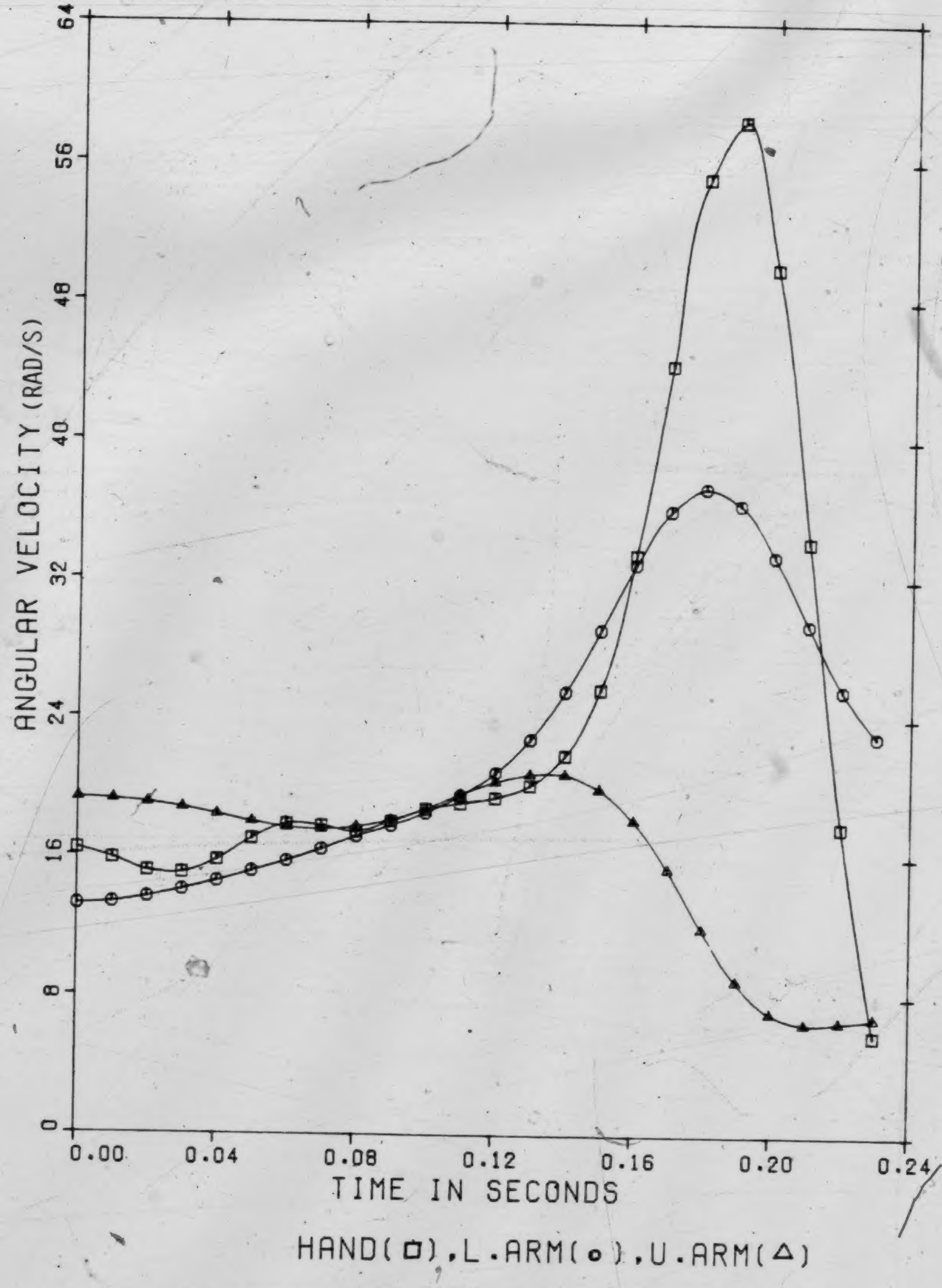


Figure 10. Angular Velocity vs Time of the Arm Segments for Subject 1.

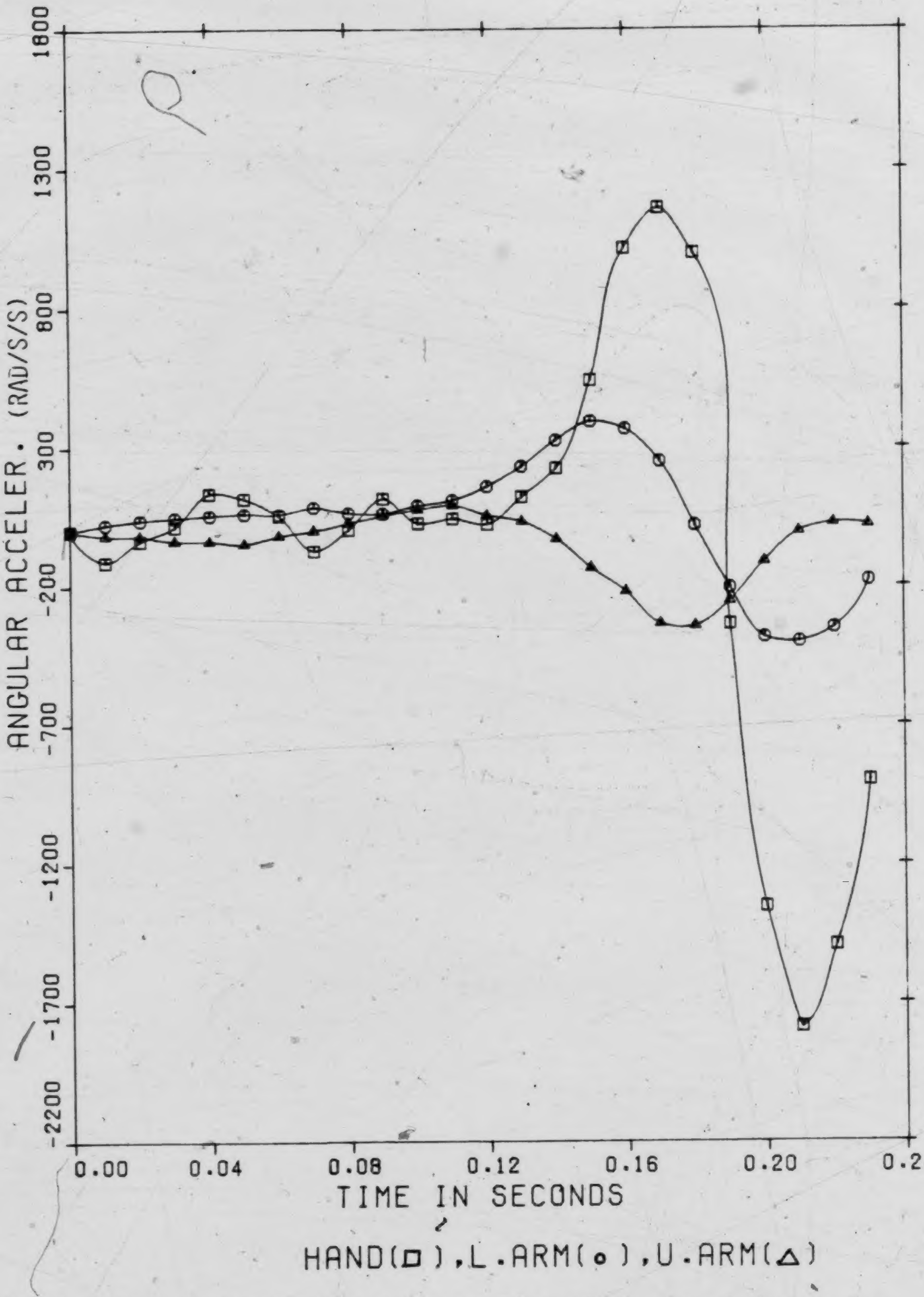


Figure 11. Angular Acceleration vs Time of the Arm Segments for Subject 1.

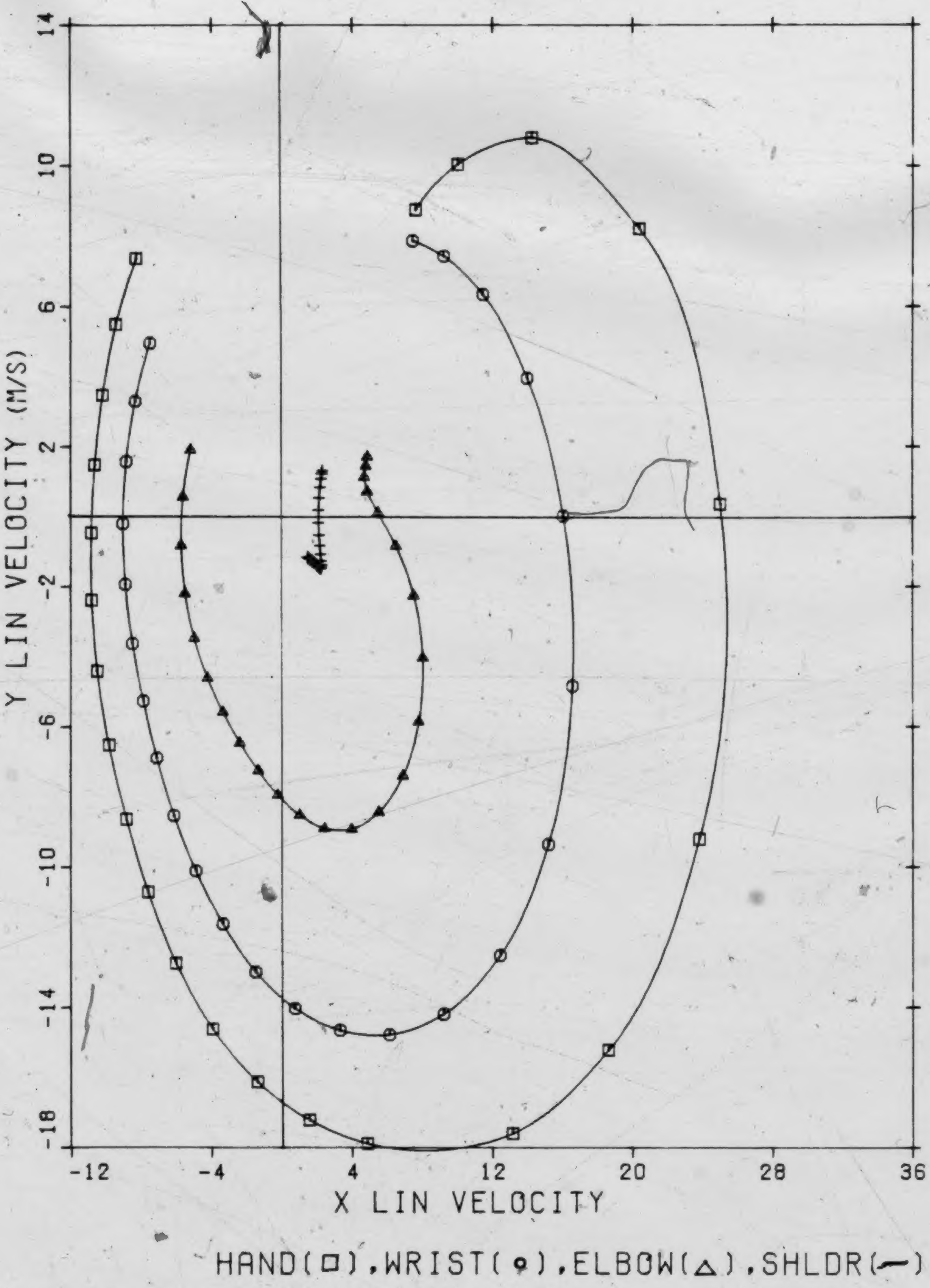


Figure 12. X and Y Linear Velocities of the Segmental Endpoints for Subject 1.

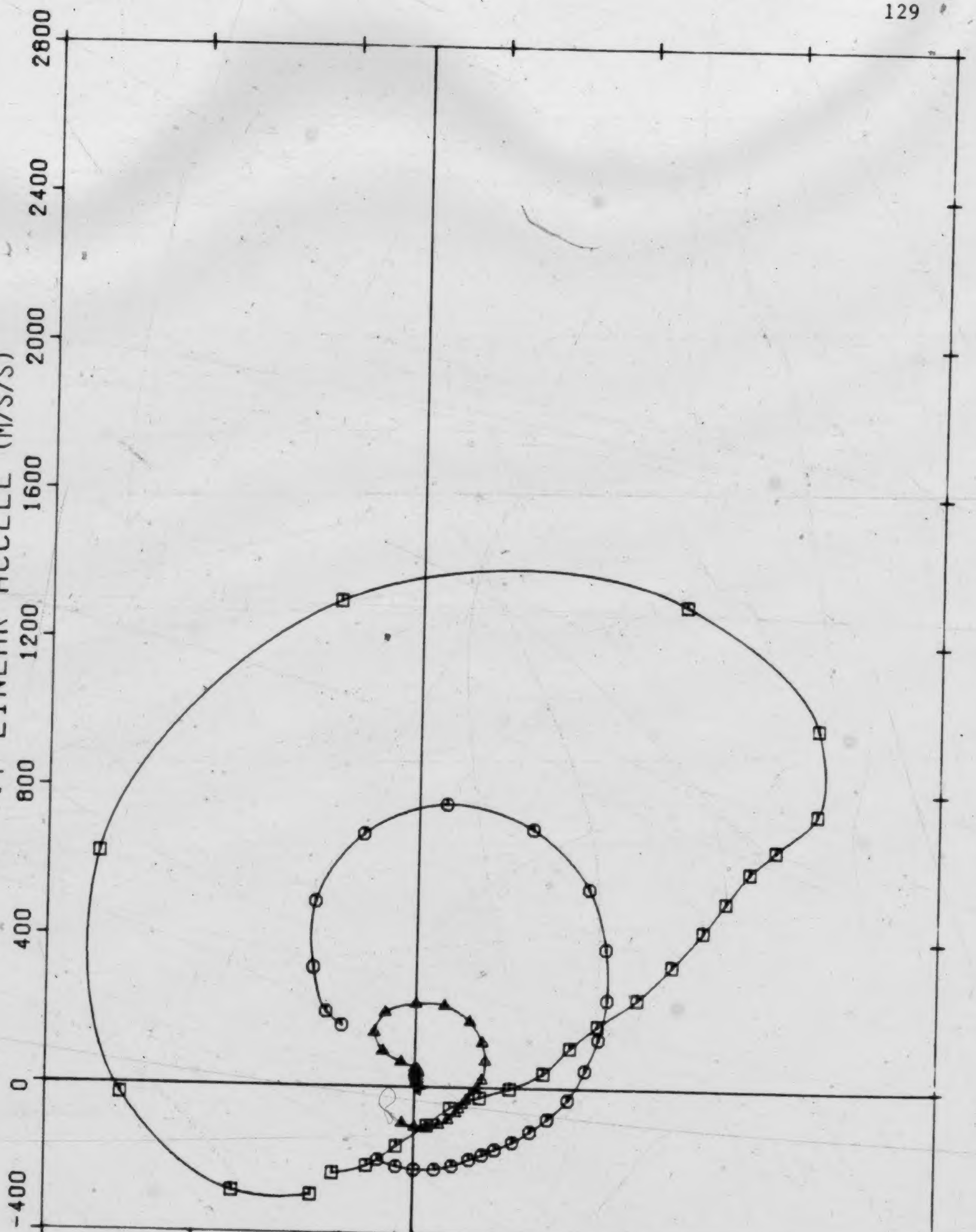


Figure 13. X and Y Linear Accelerations of the Segmental Endpoints for Subject 1.

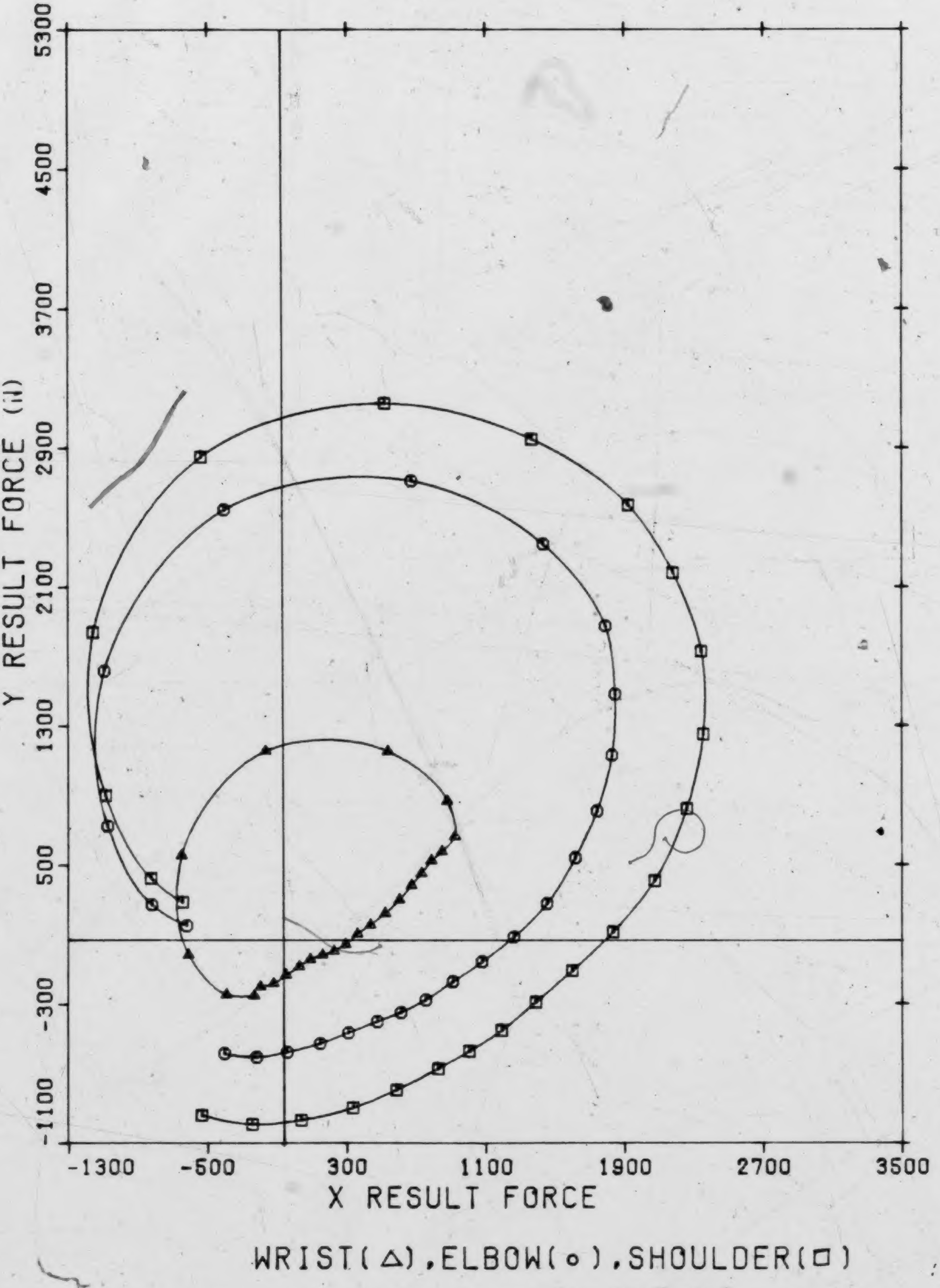


Figure 14. X and Y Joint Forces for Subject 1.

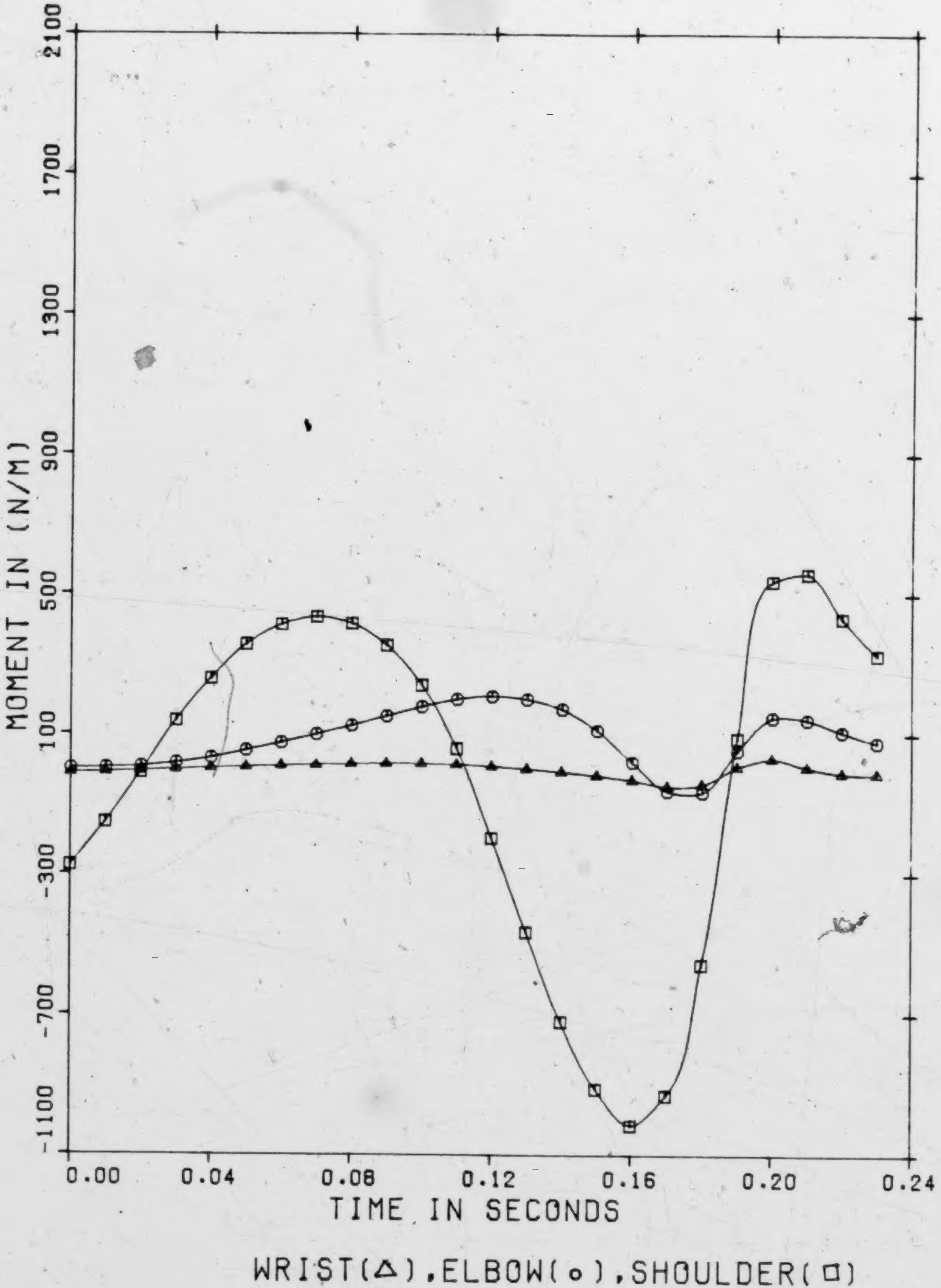
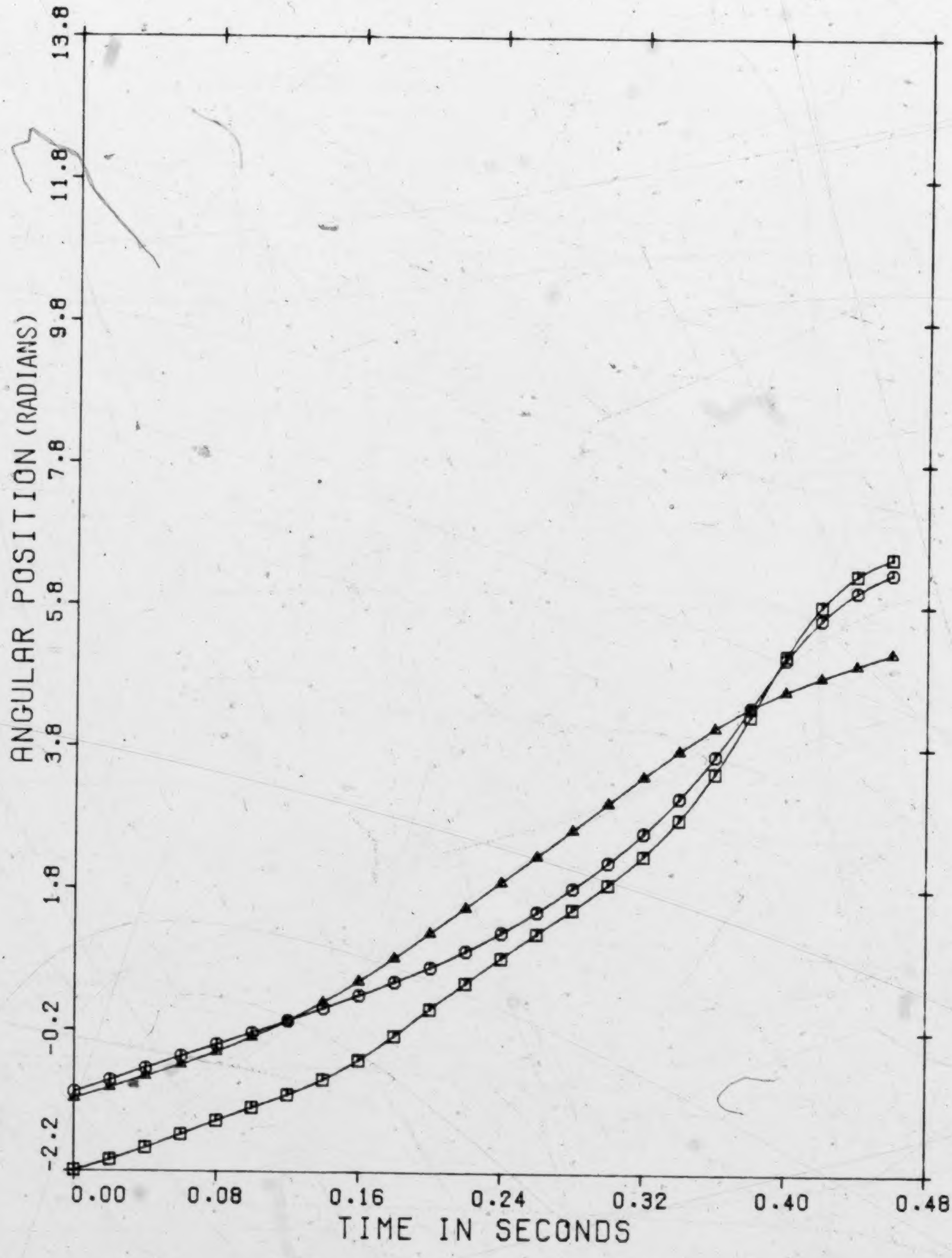


Figure 15. Resultant Moments at the Joints for Subject 1.



HAND(□),L.ARM(○),U.ARM(△)

Figure 16. Angular Position vs Time of the Arm Segments for Subject 1.

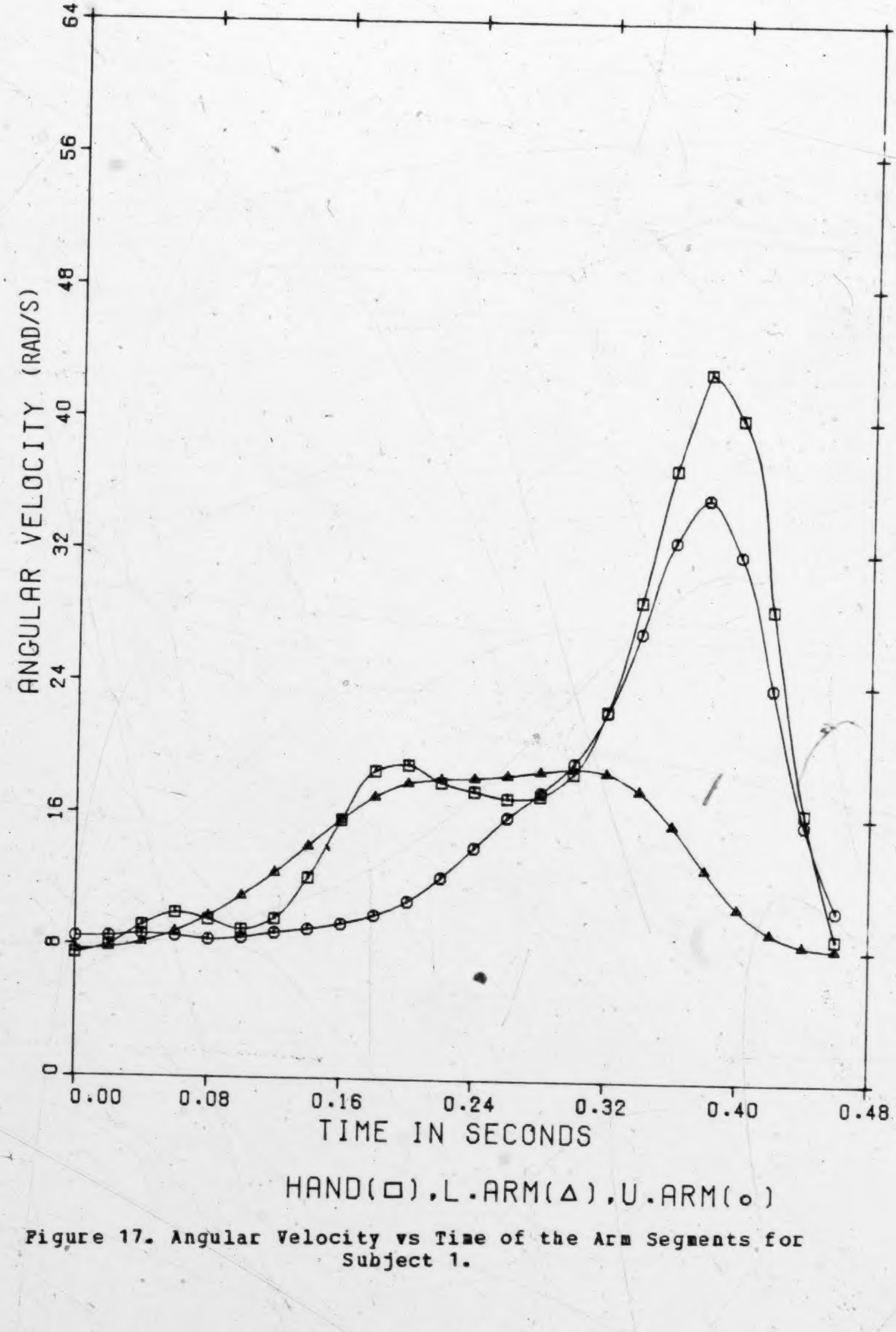


Figure 17. Angular Velocity vs Time of the Arm Segments for Subject 1.

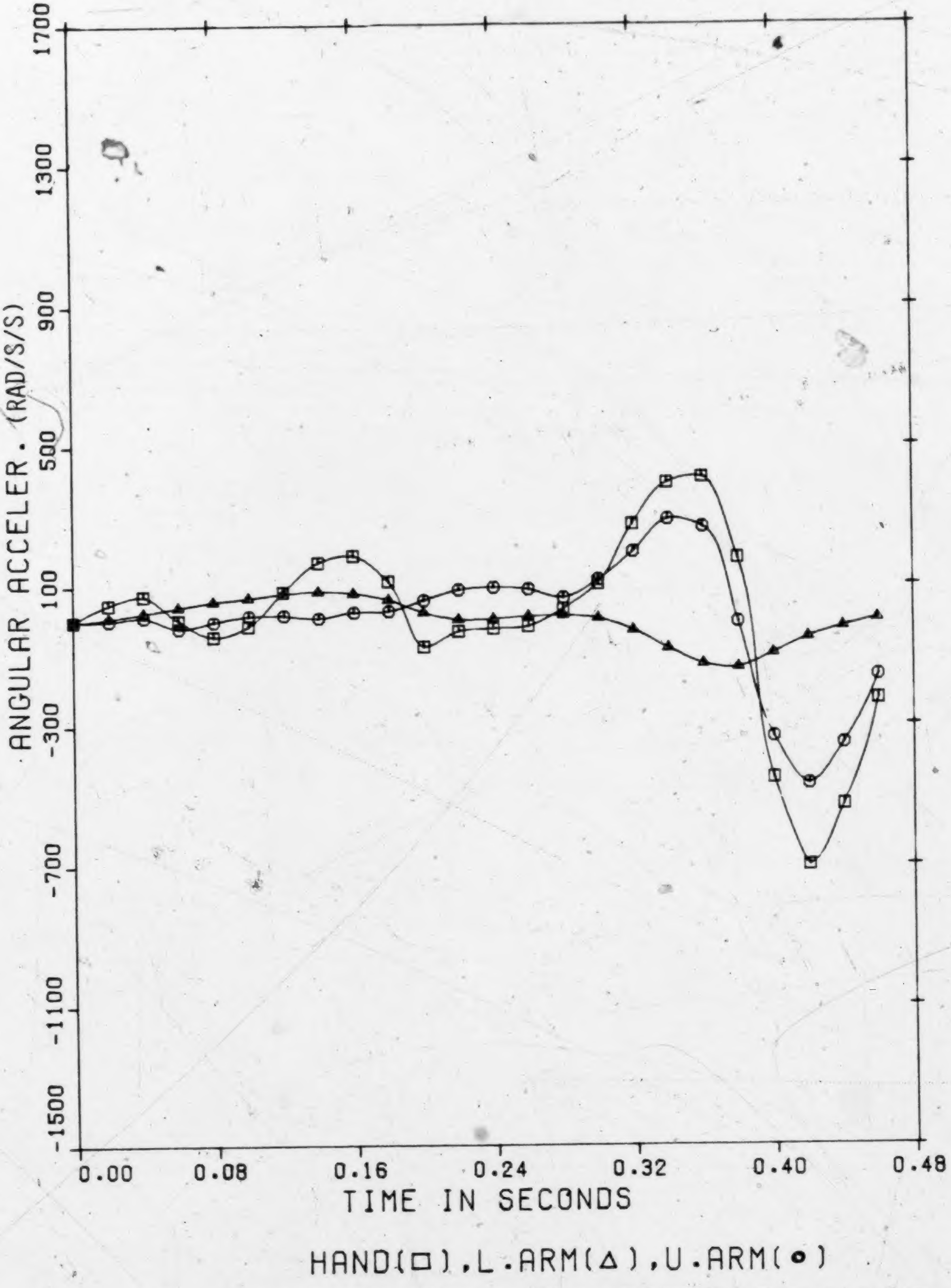


Figure 18. Angular Acceleration vs Time of the Arm Segments for Subject 1.

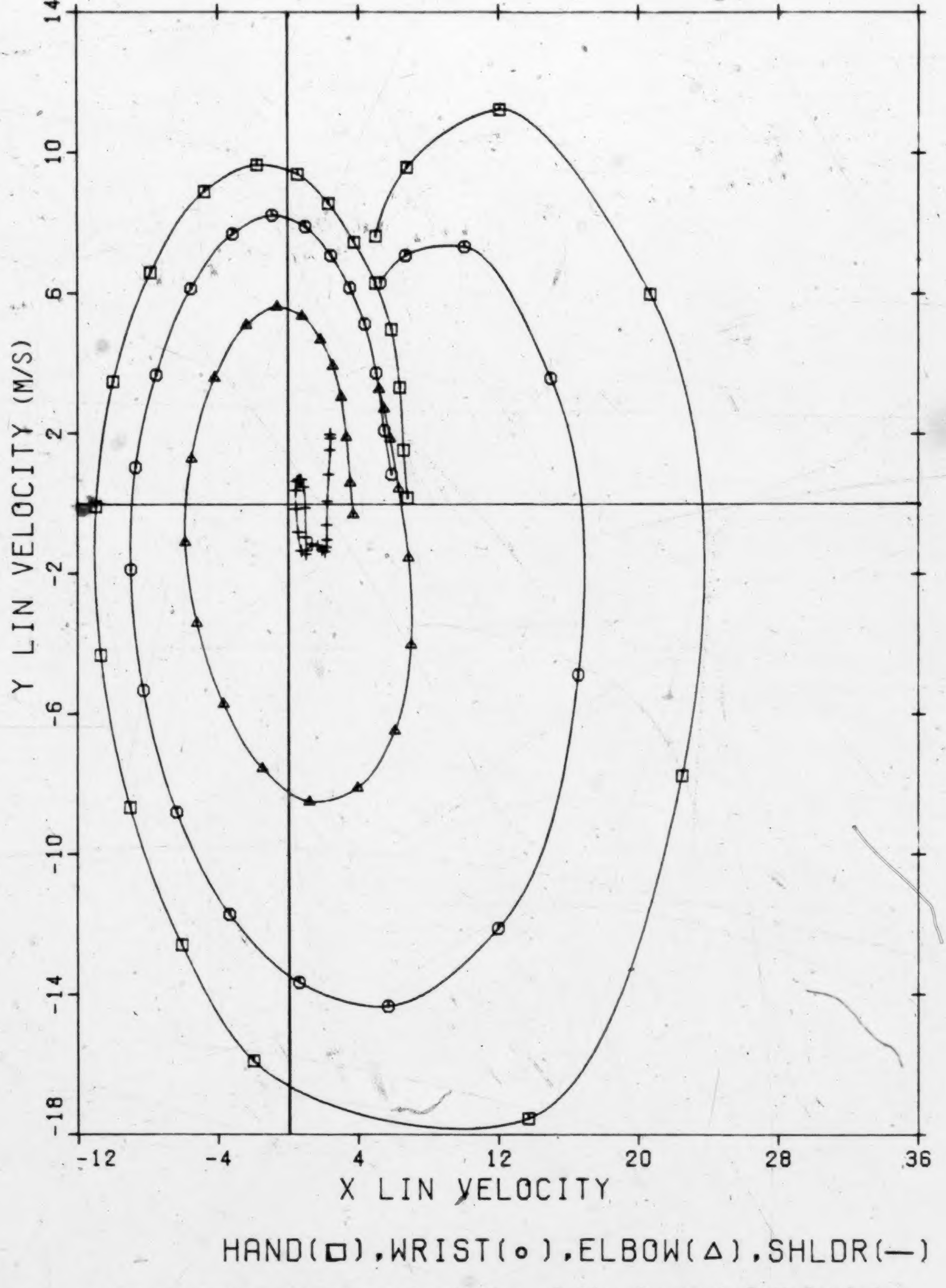


Figure 19. X and Y Linear Velocities of the Segmental Endpoints for Subject 1.

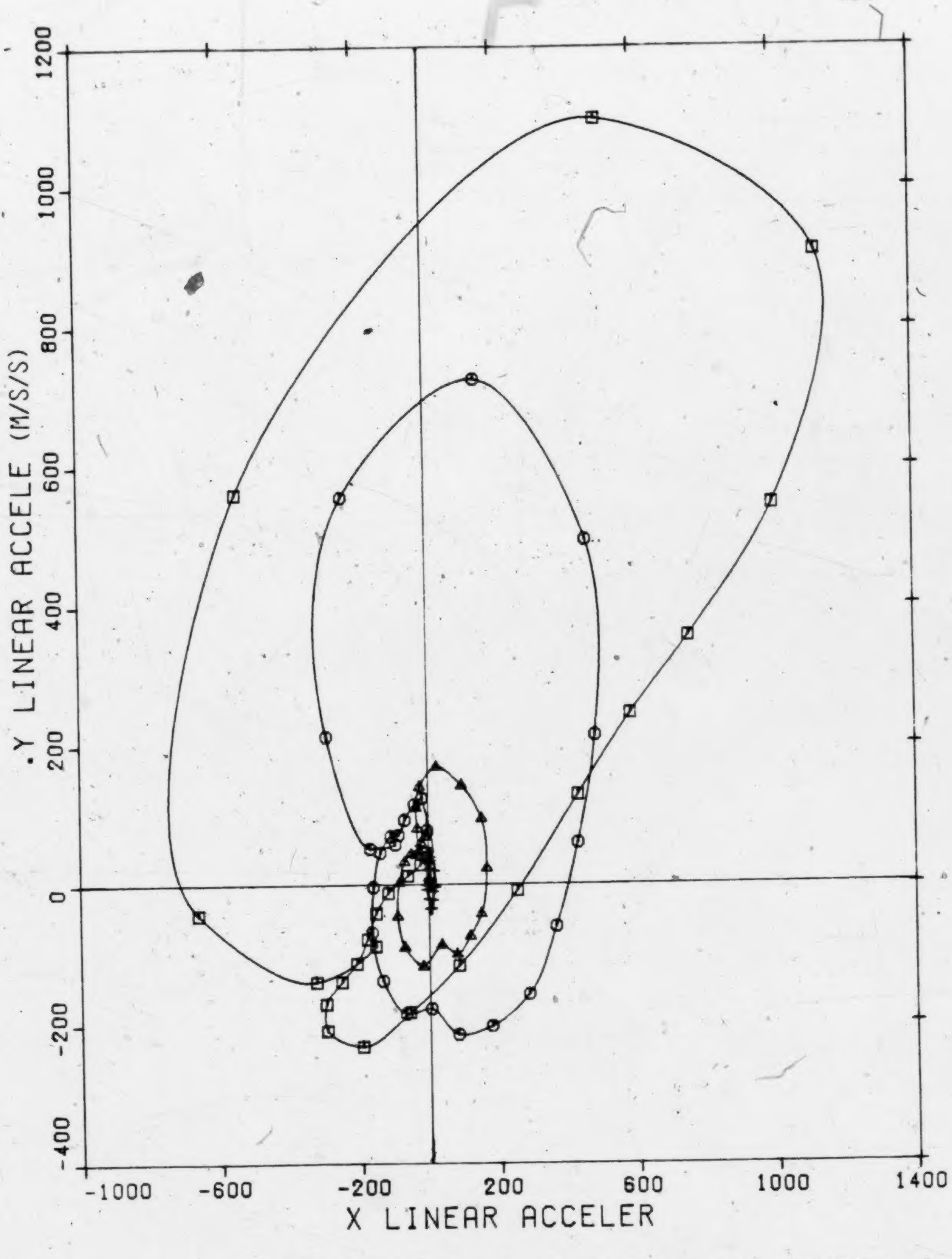


Figure 20. X and Y Linear Accelerations of the Segmental Endpoints for Subject 1.

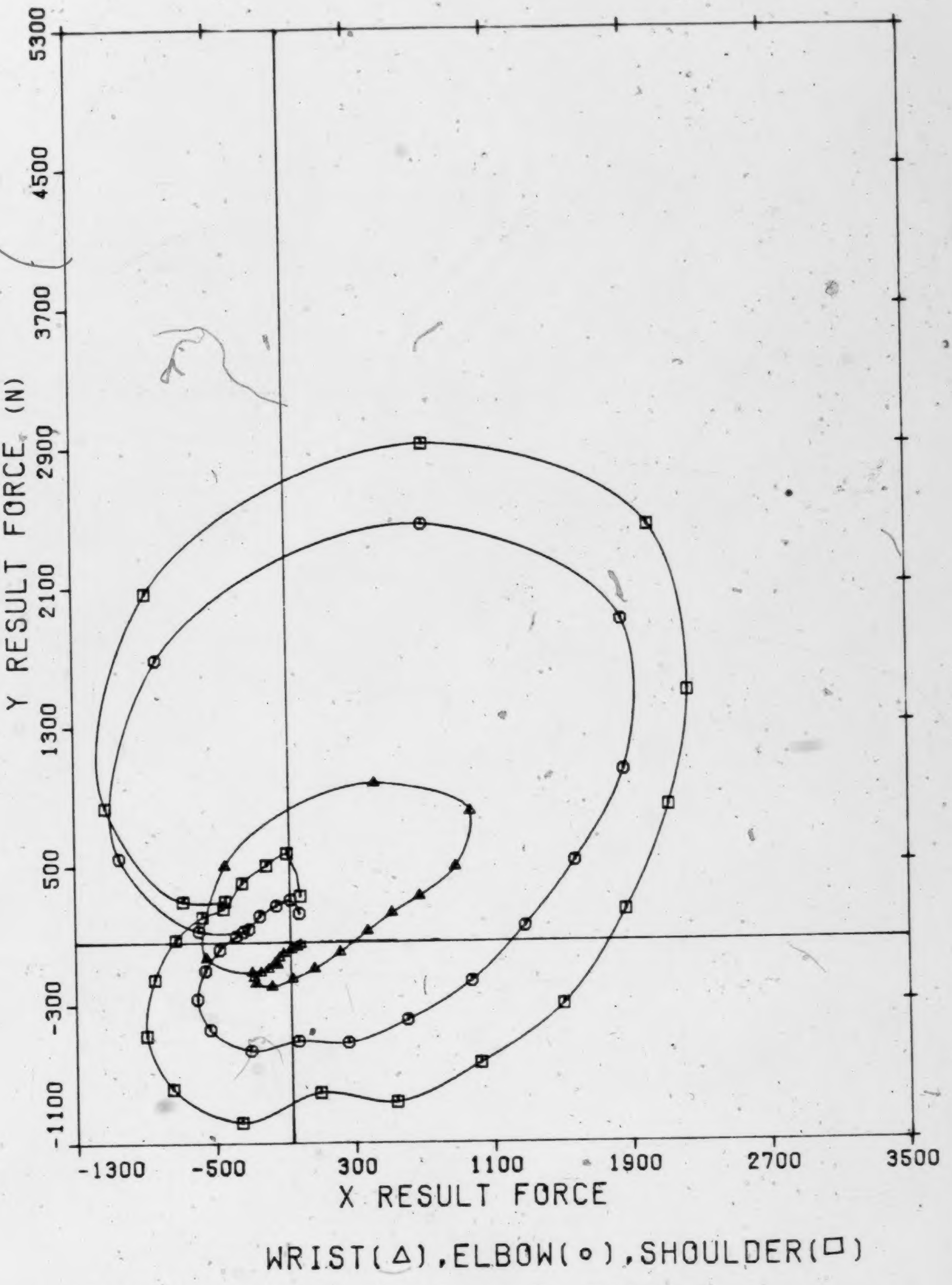


Figure 21. X and Y Joint Forces for Subject 1.

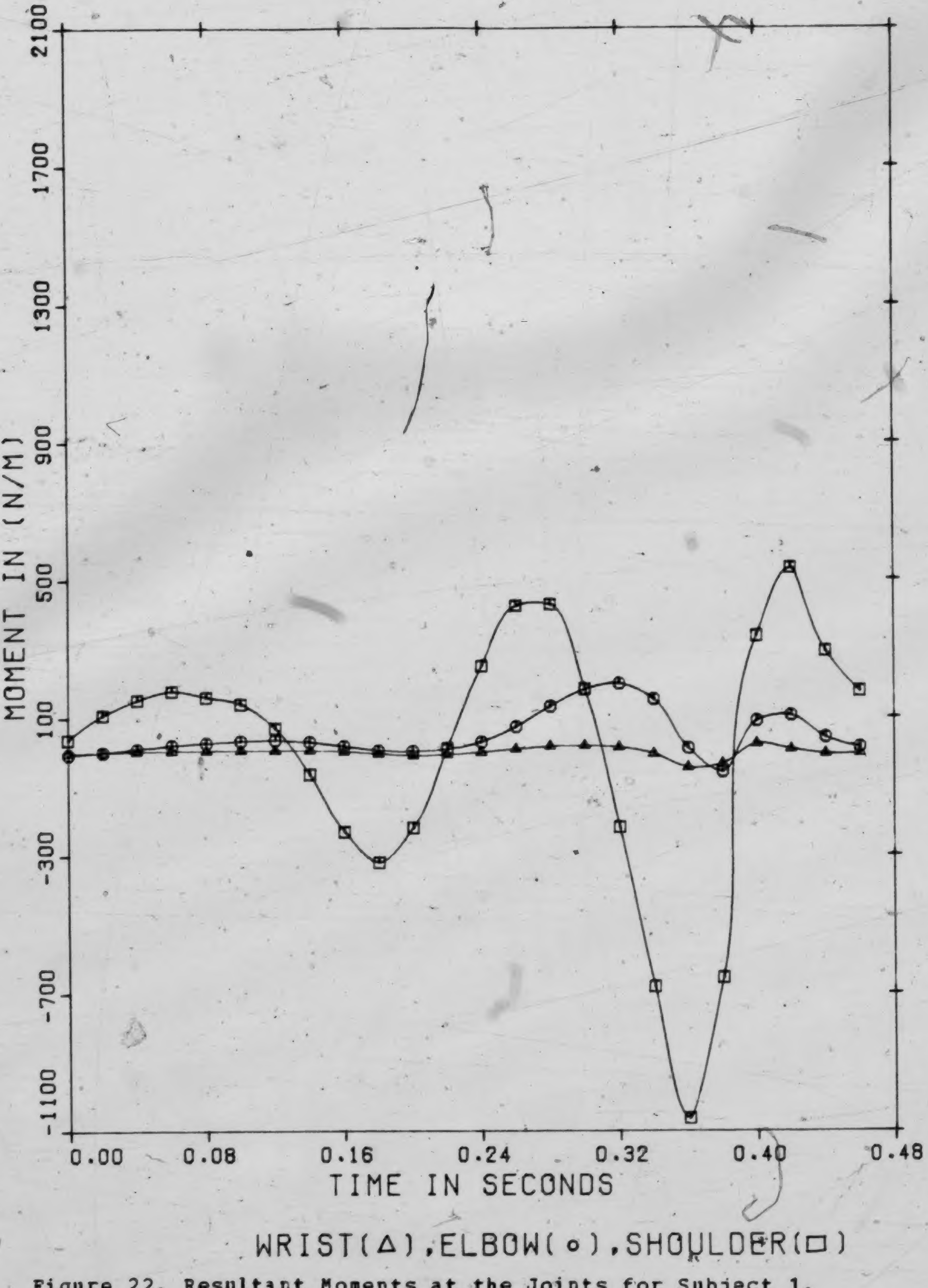


Figure 22. Resultant Moments at the Joints for Subject 1.

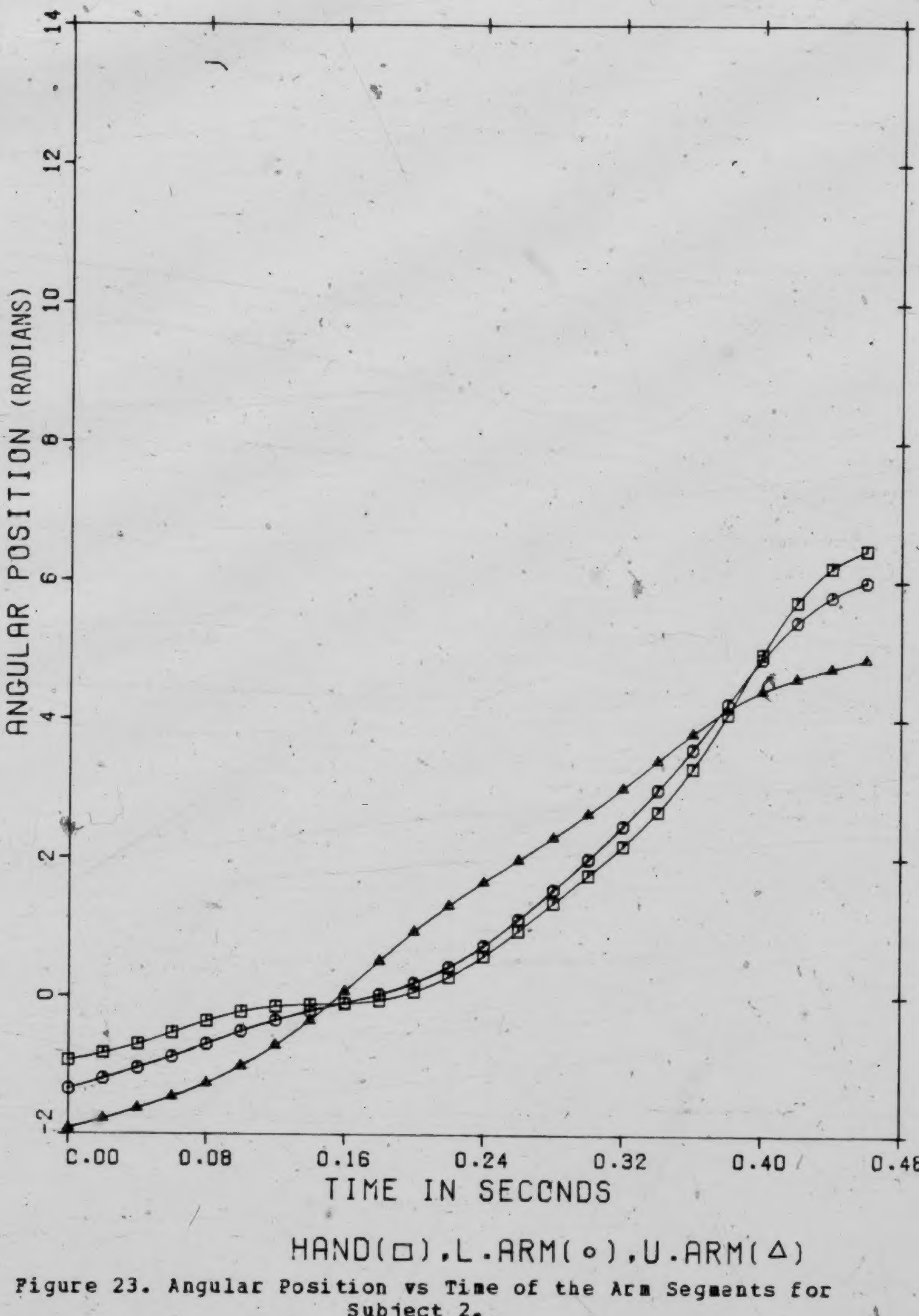


Figure 23. Angular Position vs Time of the Arm Segments for Subject 2.

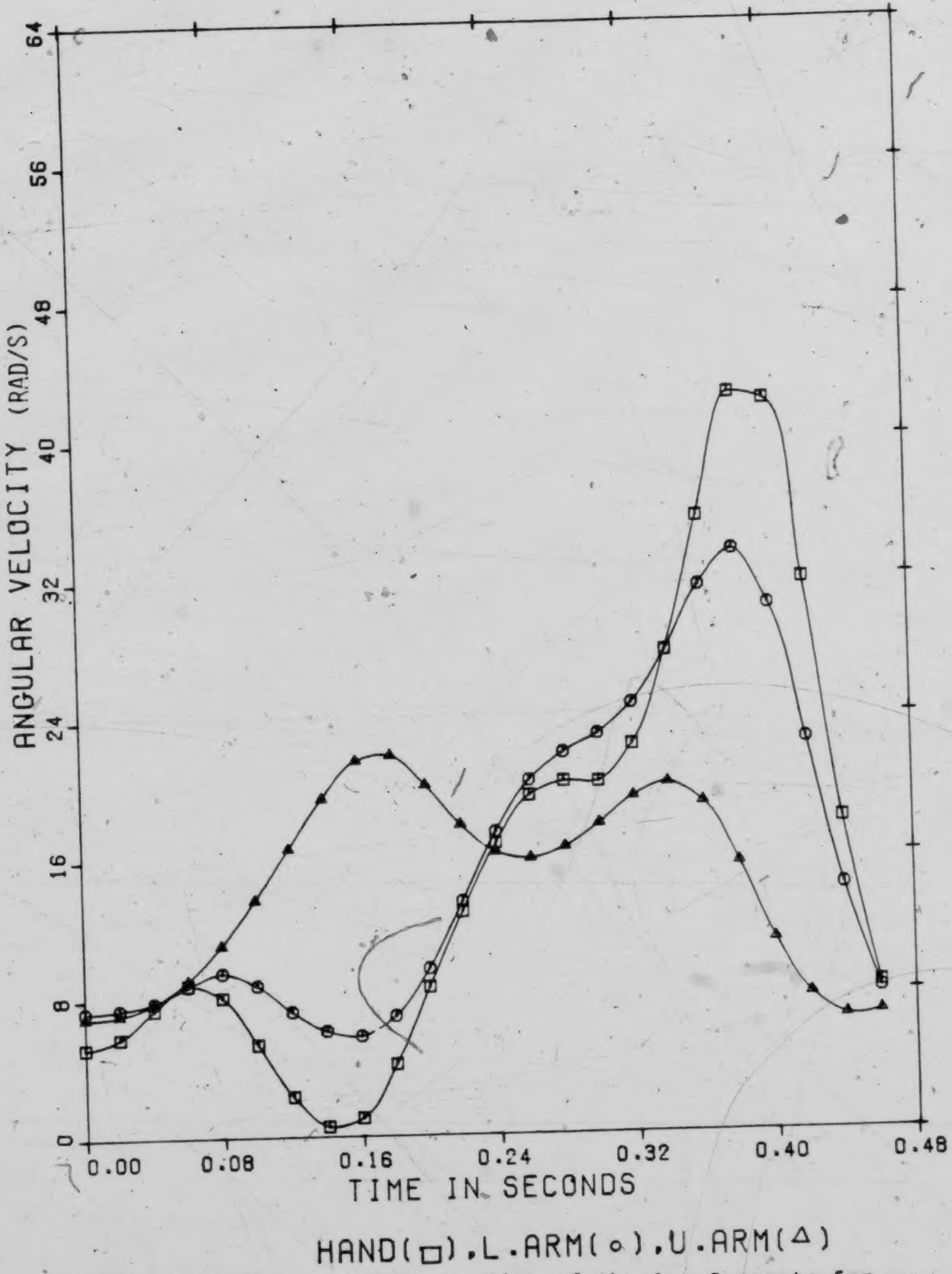


Figure 24. Angular Velocity vs Time of the Arm Segments for Subject 2.

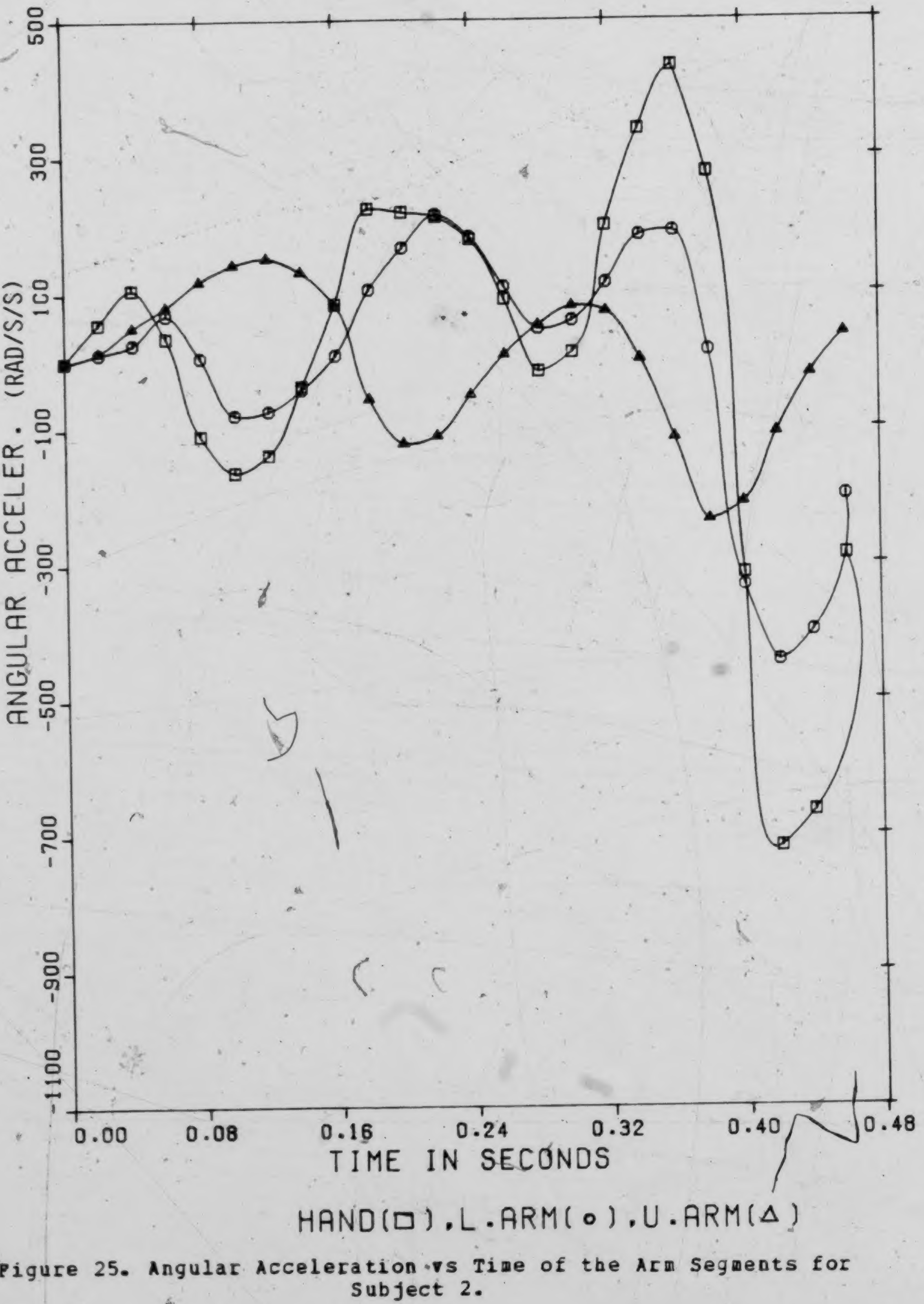


Figure 25. Angular Acceleration vs Time of the Arm Segments for Subject 2.

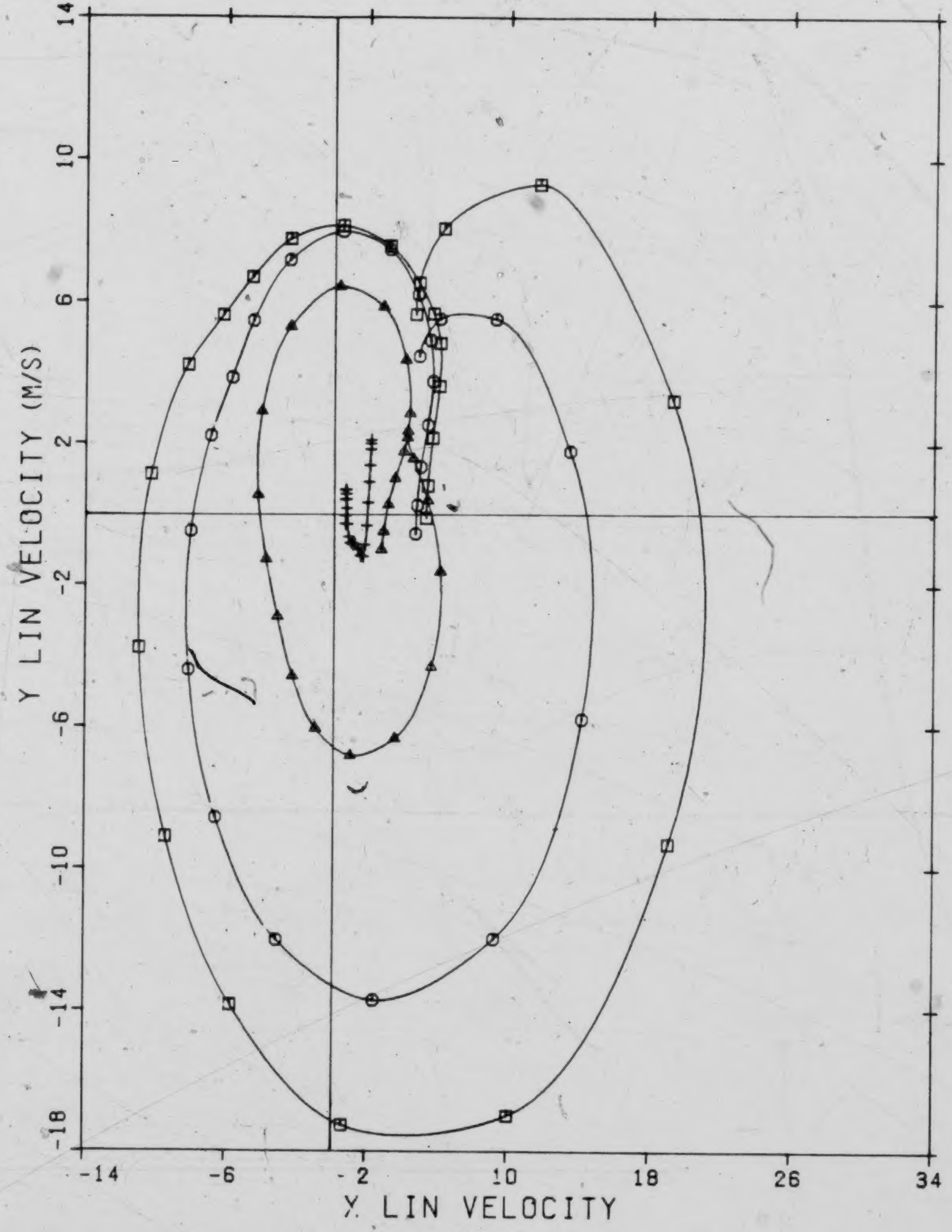


Figure 26. X and Y Linear Velocities of the Segmental Endpoints for Subject 2.

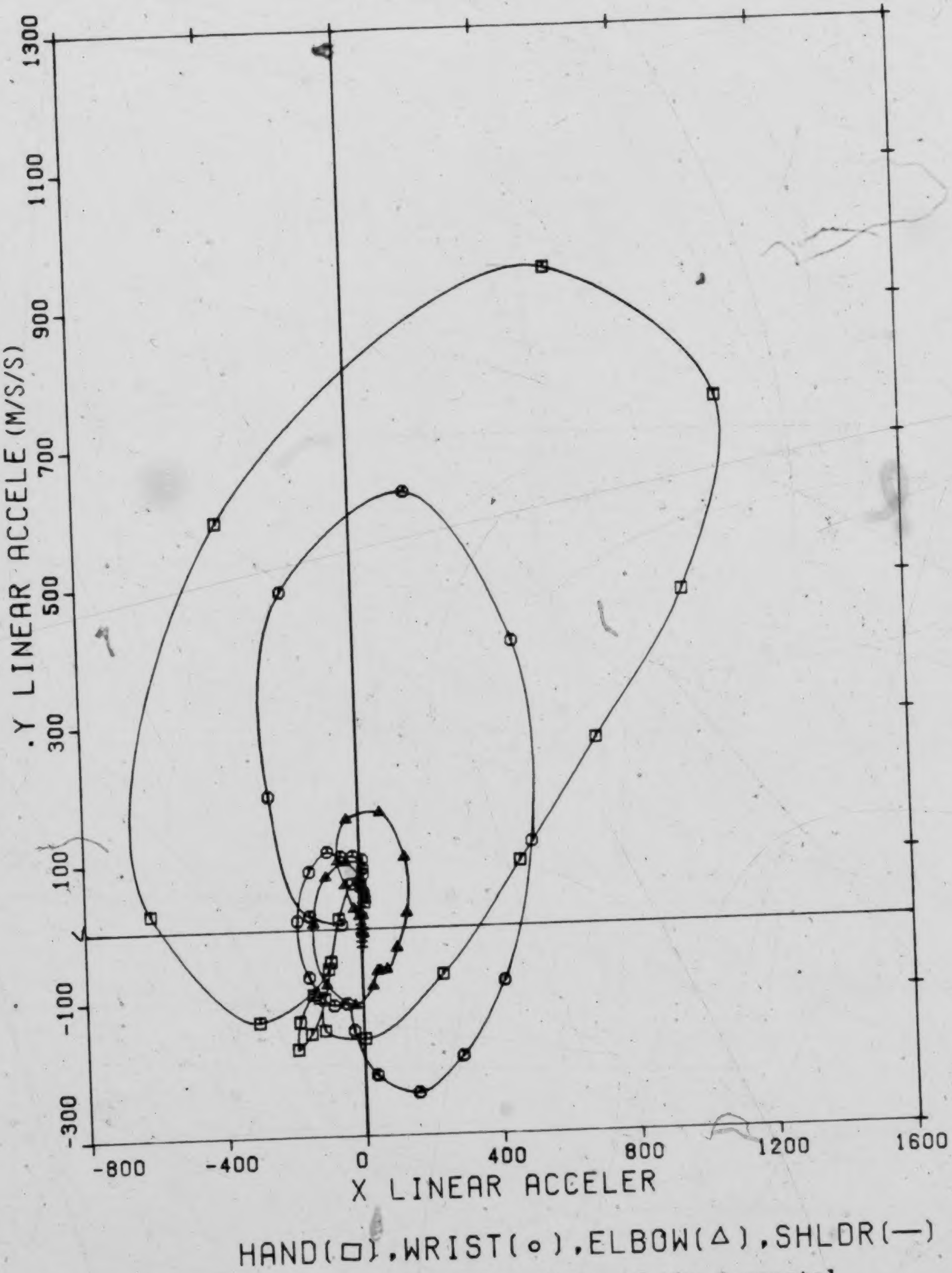


Figure 27. X and Y Linear Accelerations of the Segmental Endpoints for Subject 2.

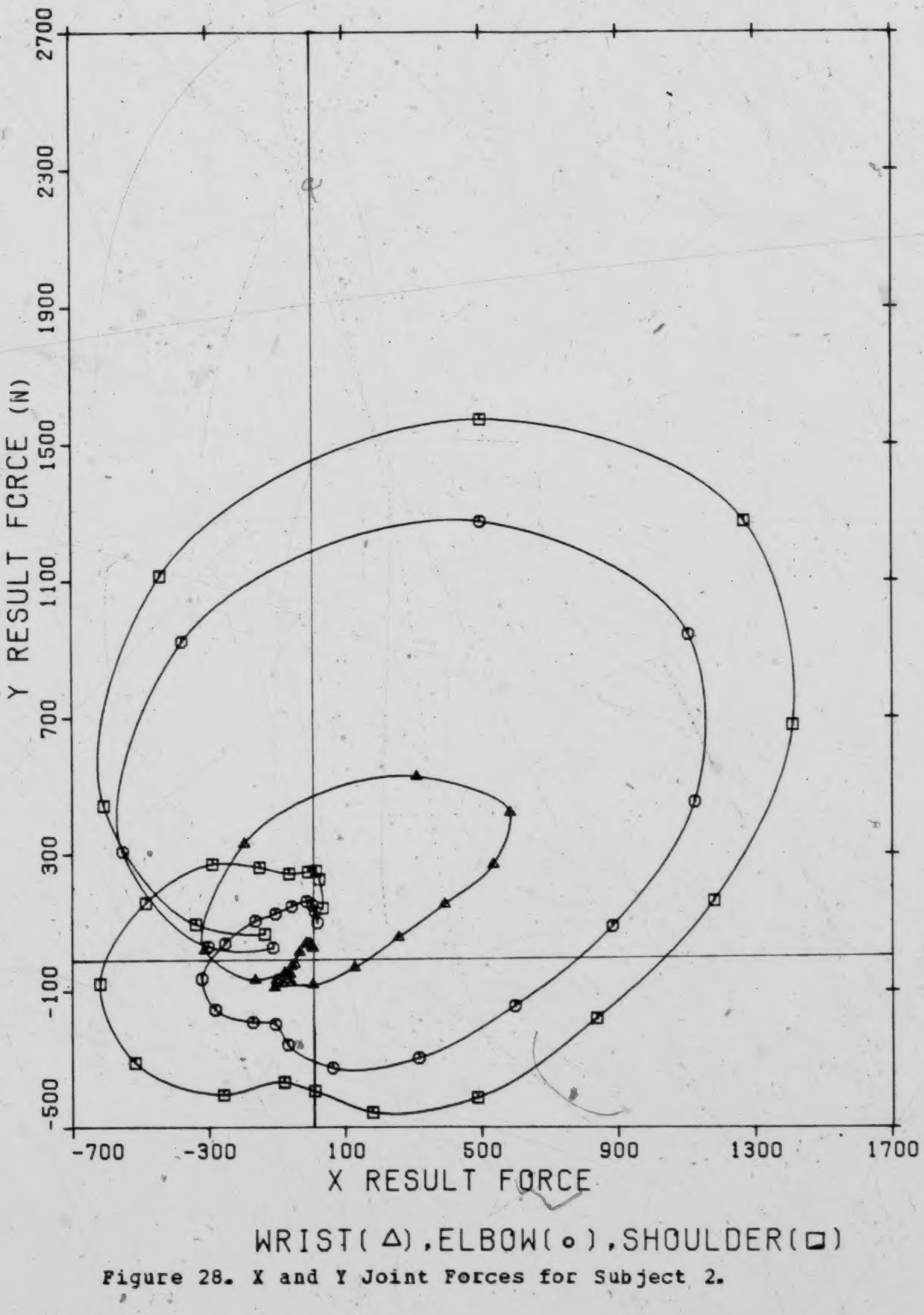


Figure 28. X and Y Joint Forces for Subject 2.

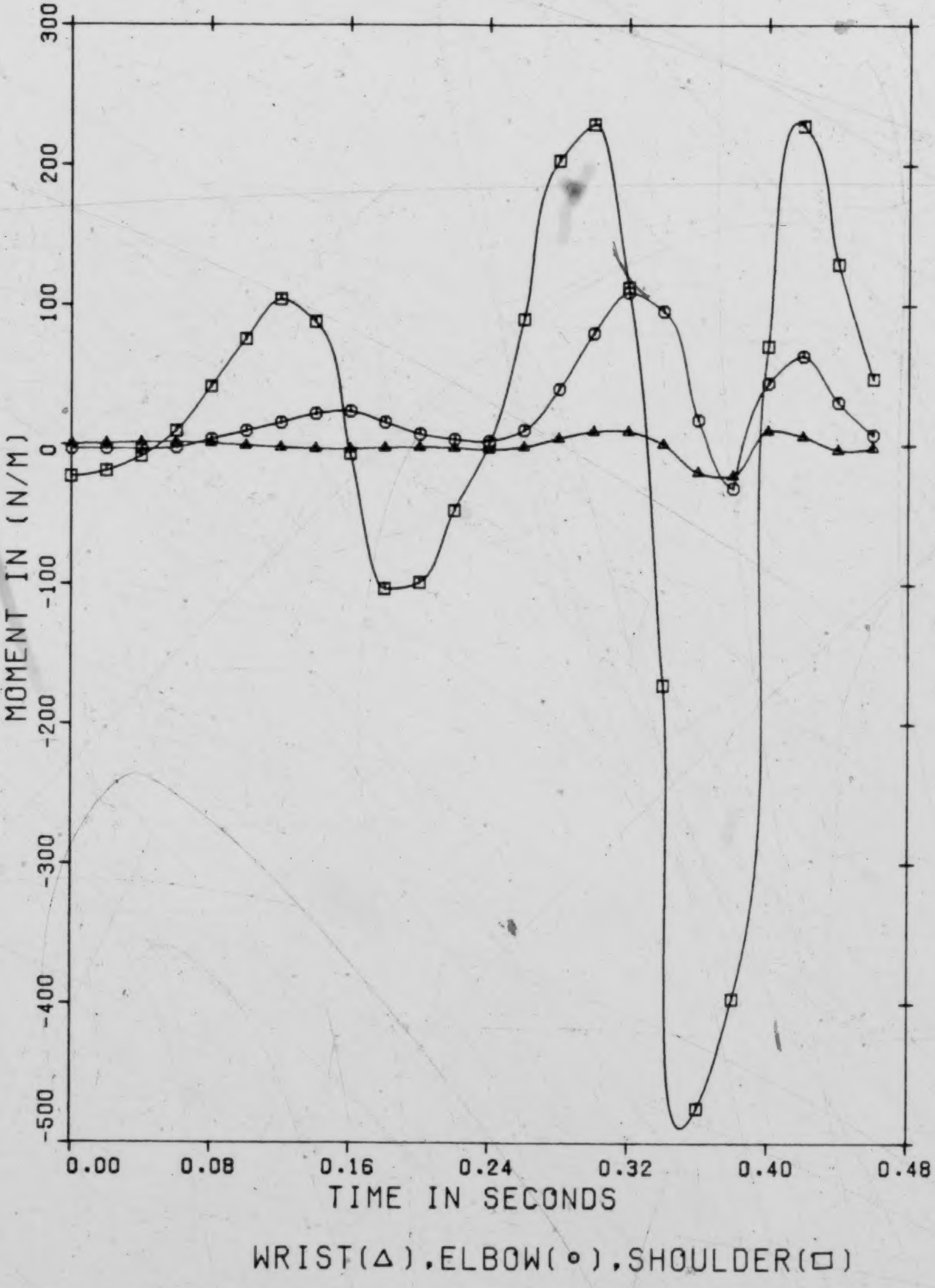


Figure 29. Resultant Moments at the Joints for Subject 2.

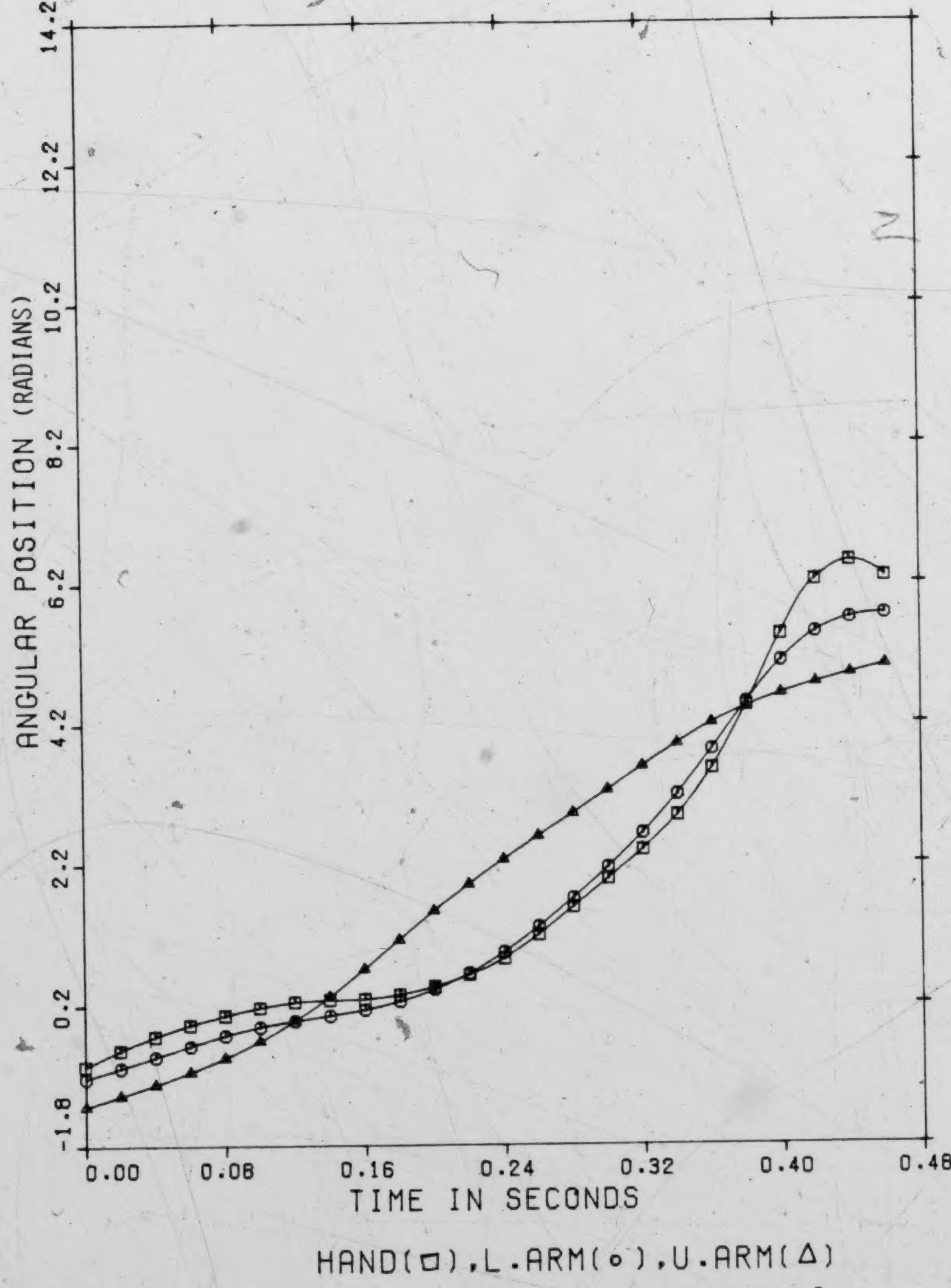


Figure 30. Angular Position vs Time of the Arm Segments for Subject 3.

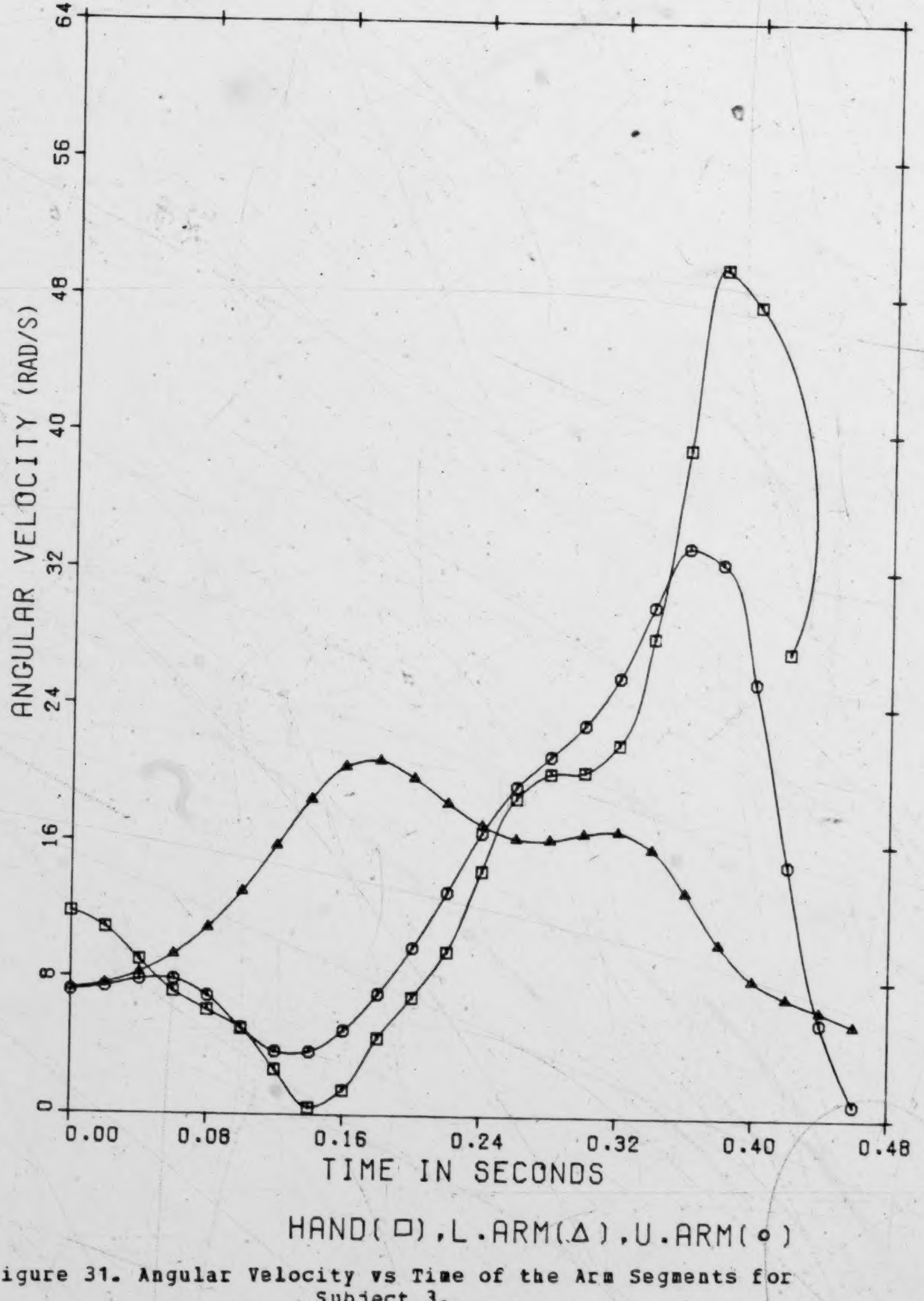


Figure 31. Angular Velocity vs Time of the Arm Segments for Subject 3.

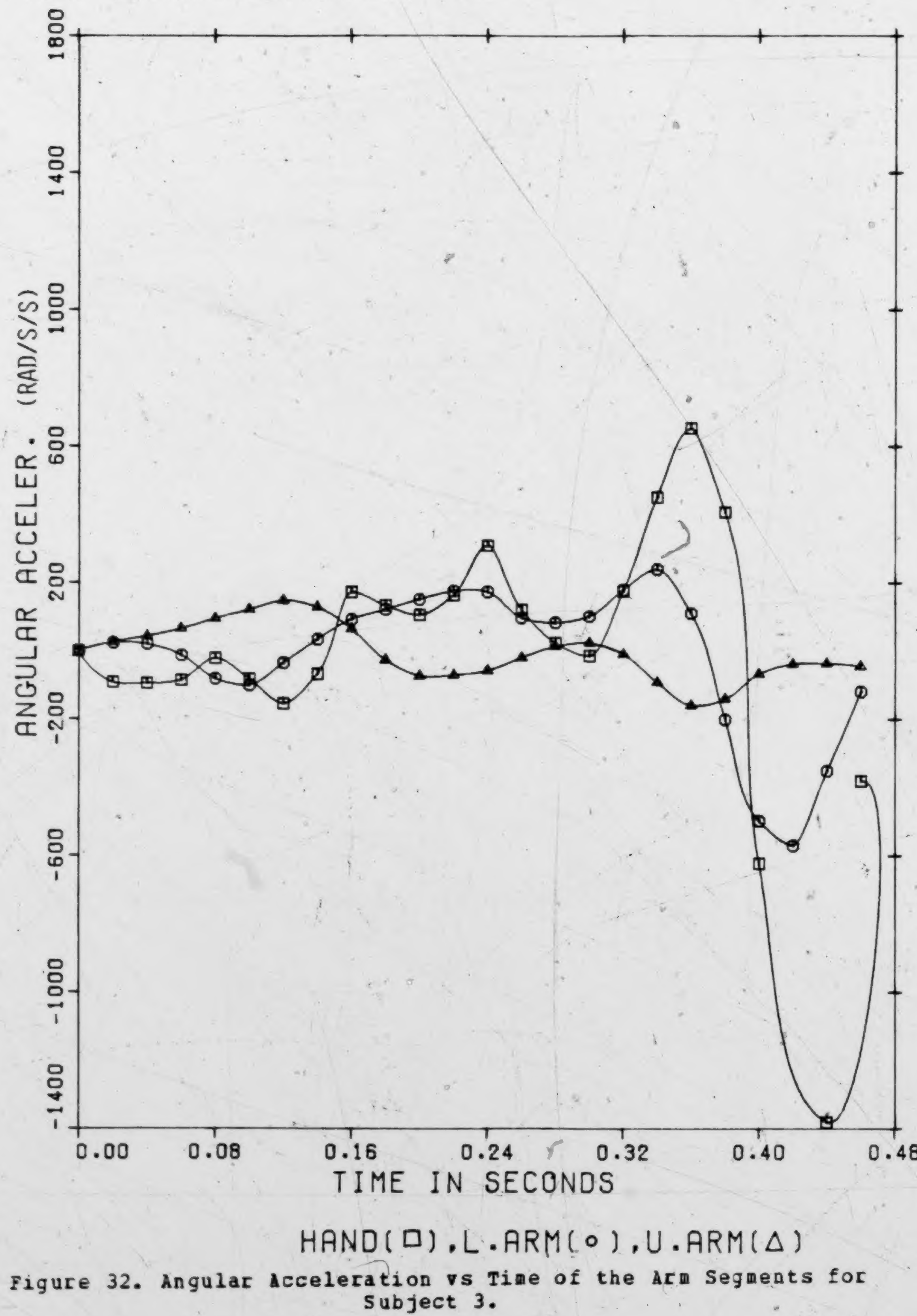


Figure 32. Angular Acceleration vs Time of the Arm Segments for Subject 3.

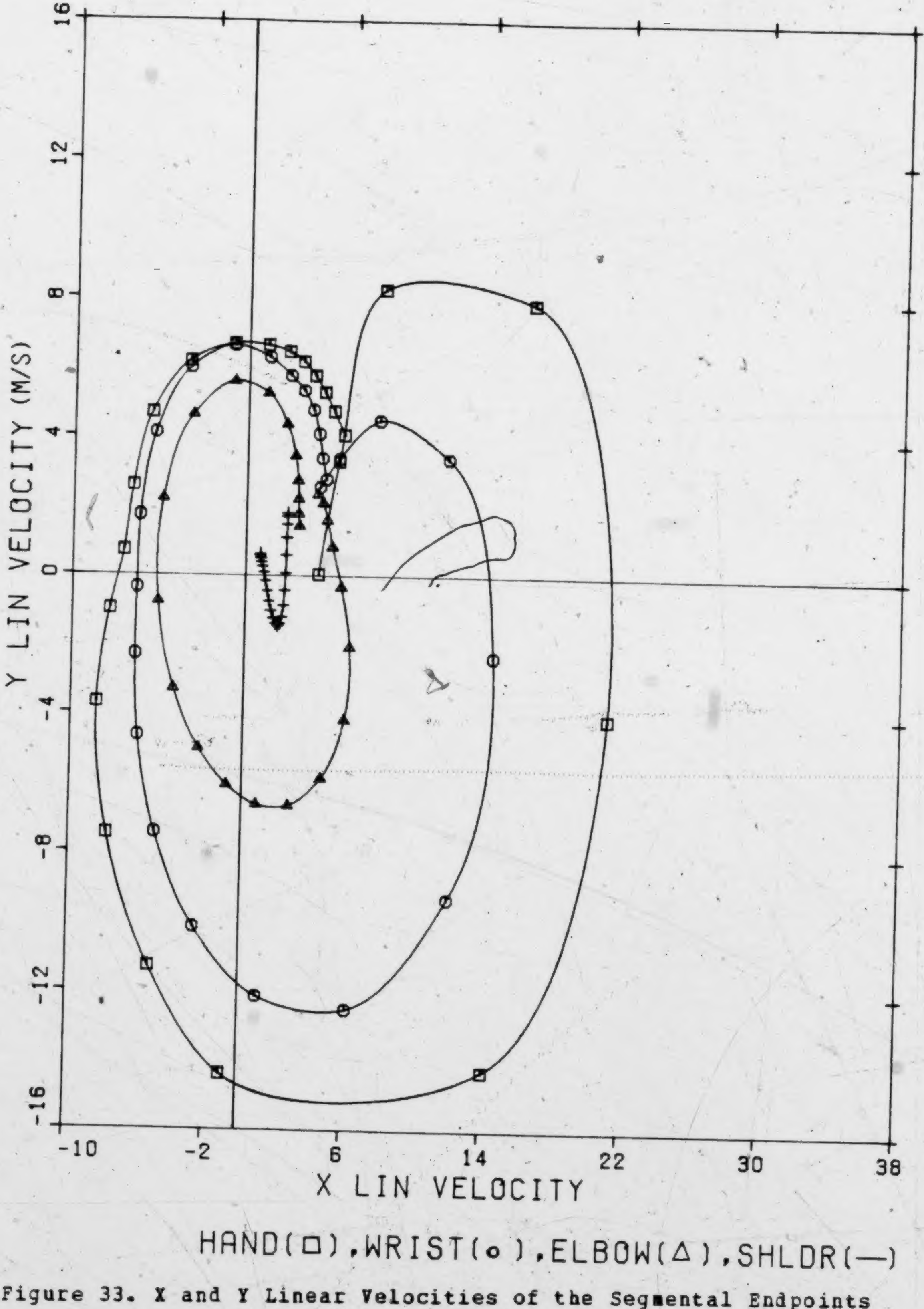


Figure 33. X and Y Linear Velocities of the Segmental Endpoints for Subject 3.

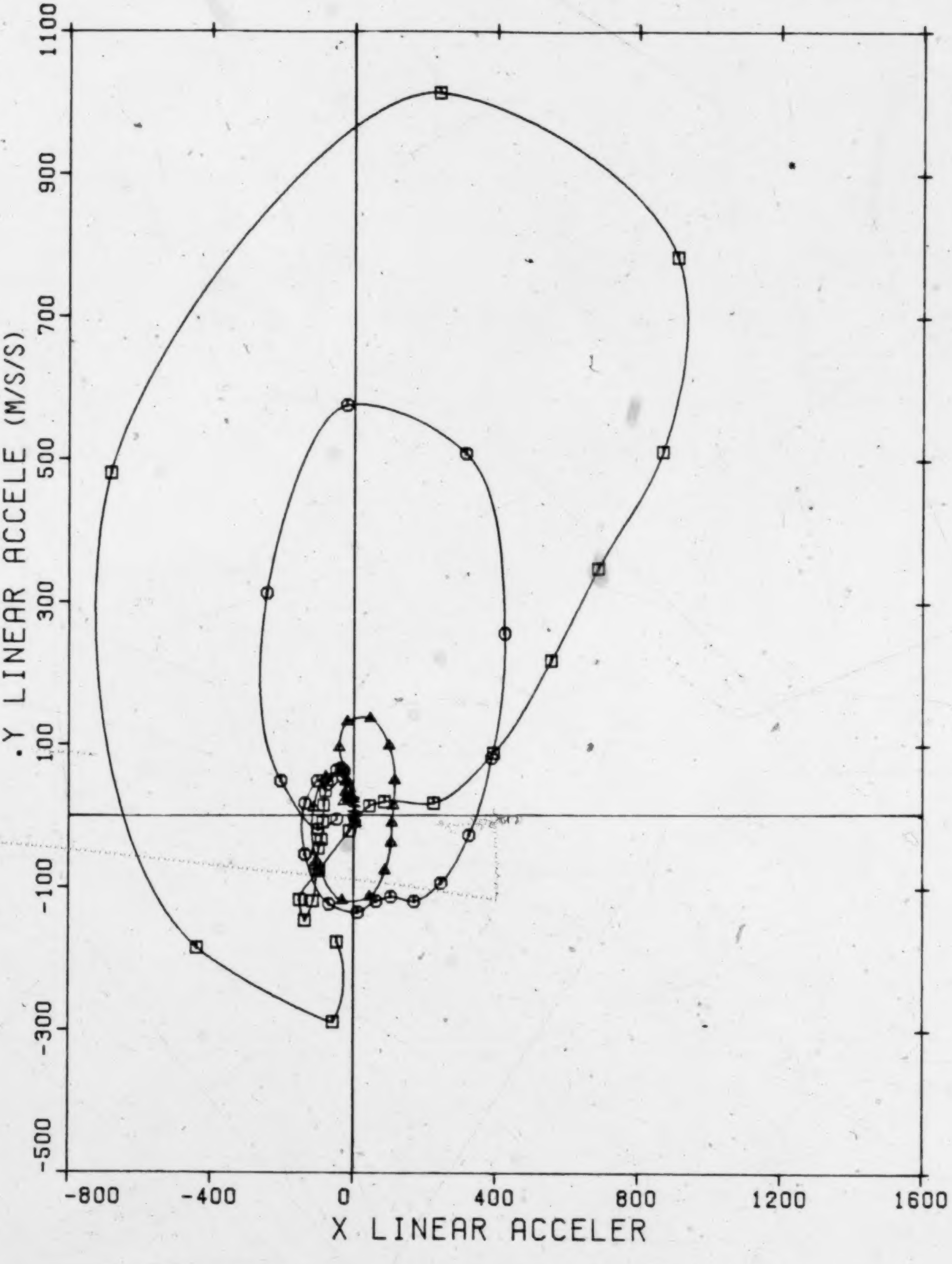


Figure 34. X and Y Linear Accelerations of the Segmental Endpoints for Subject 3.

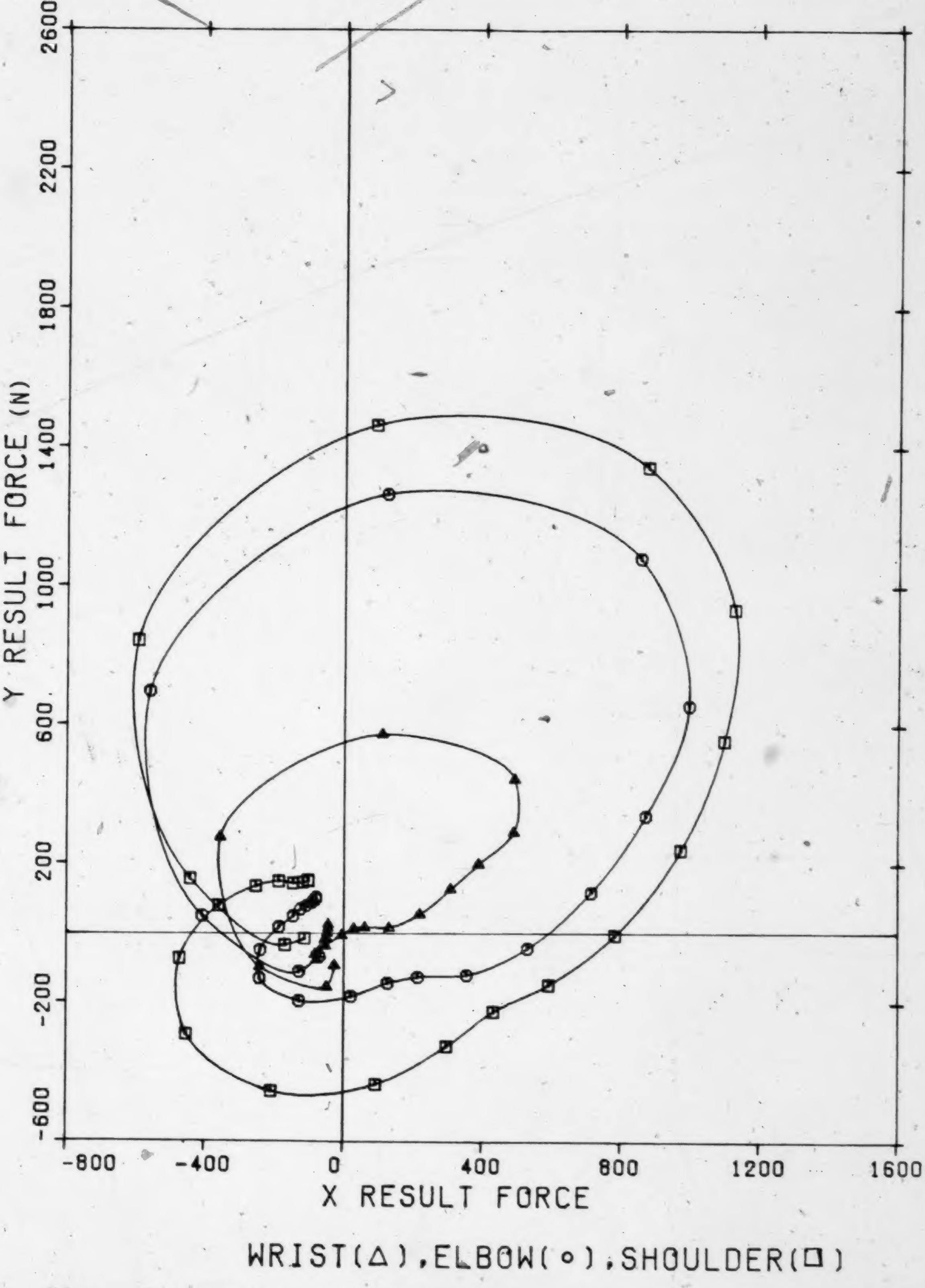


Figure 35. X and Y Joint Forces for Subject 3.

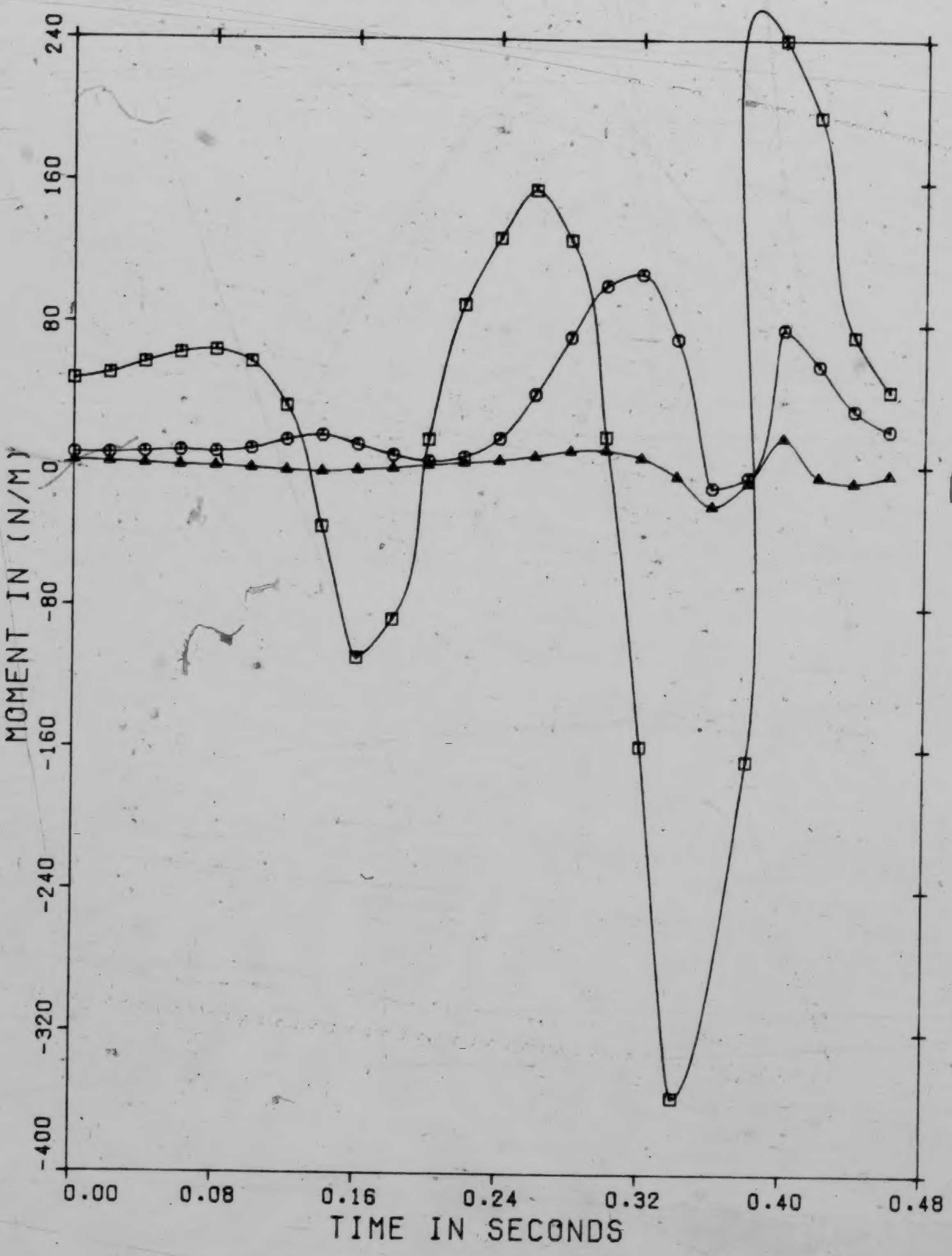


Figure 36. Resultant Moments at the Joints for Subject 3.

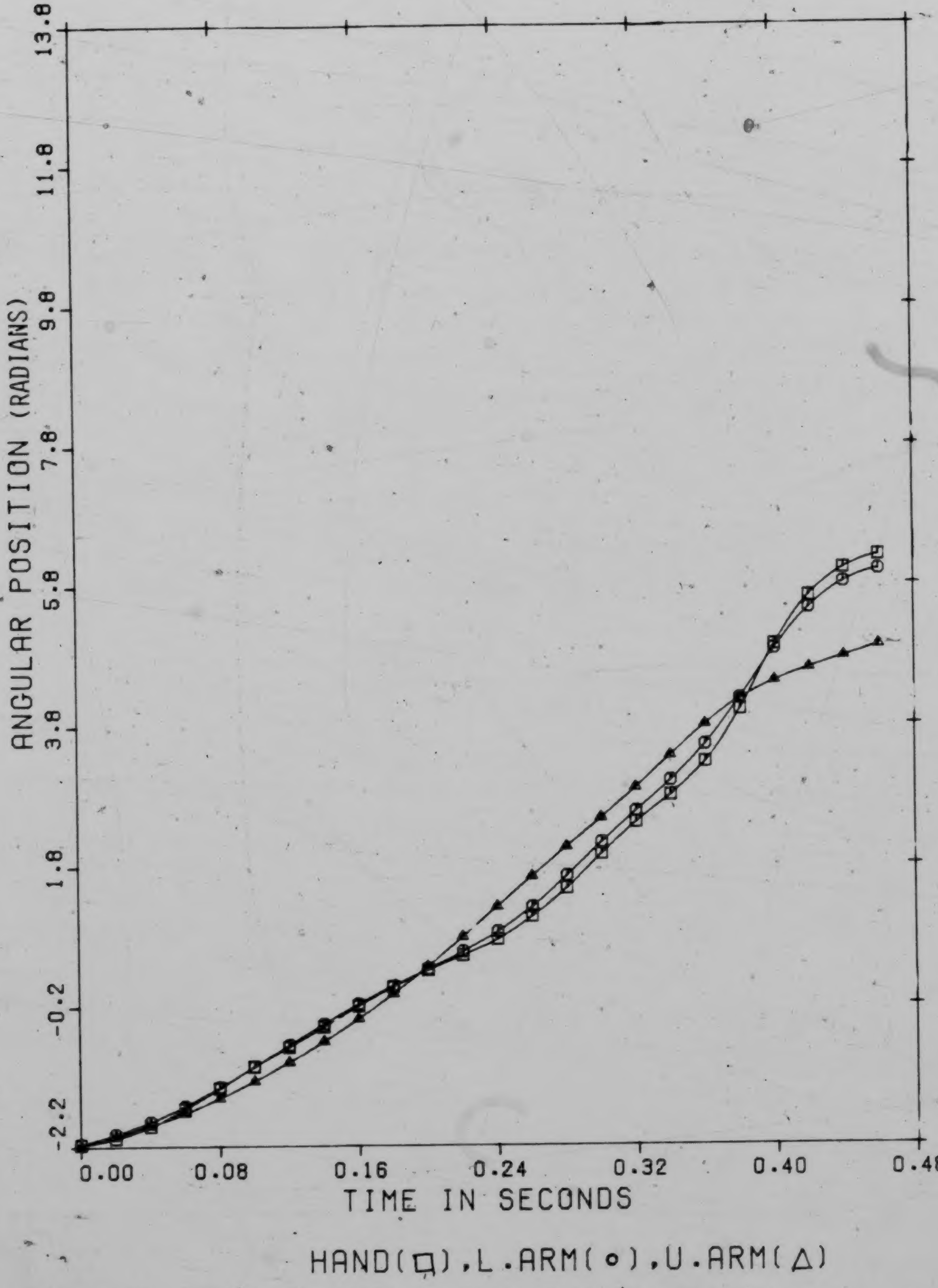


Figure 37. Angular Position vs Time of the Arm Segments for Subject 4.

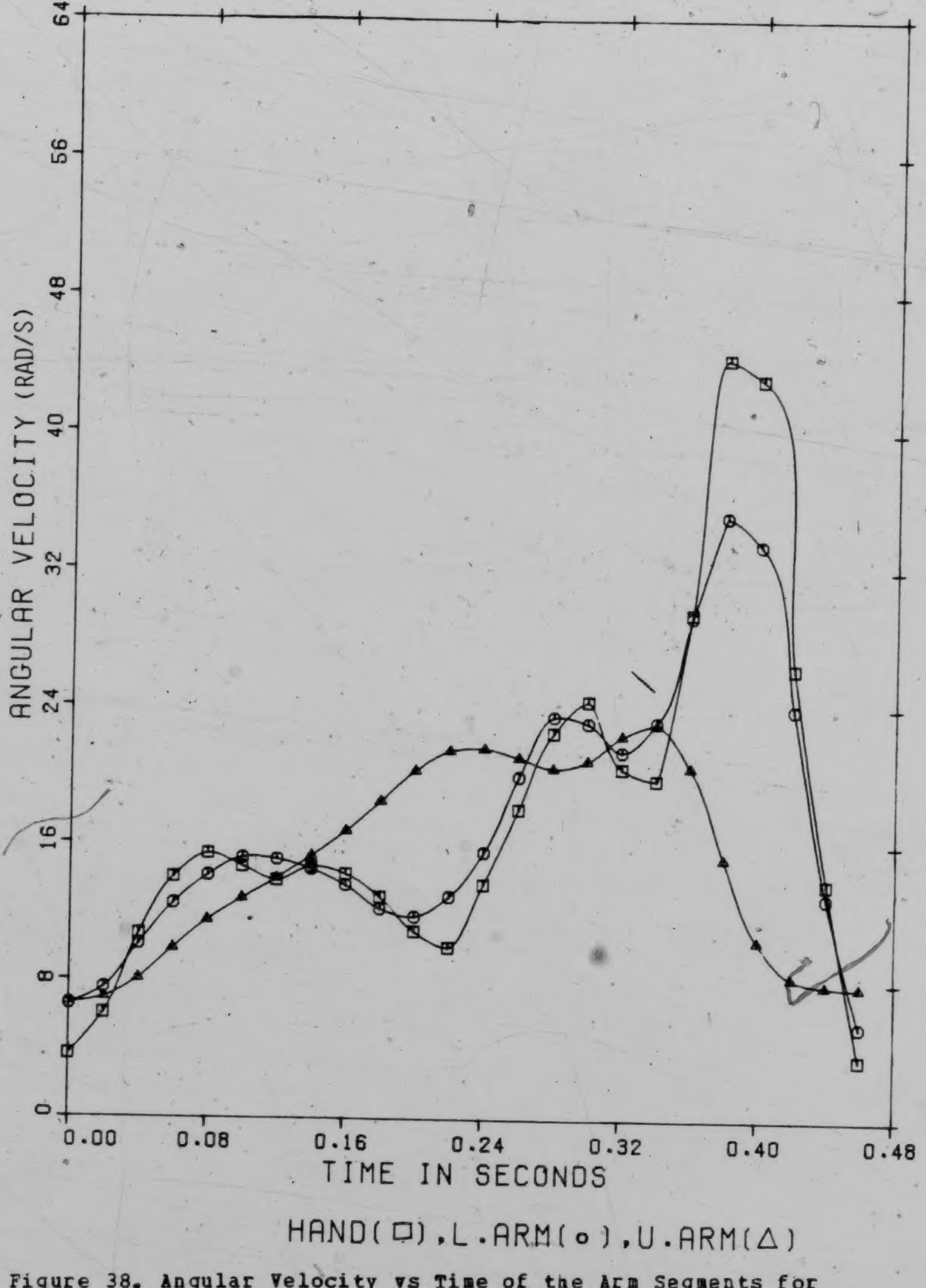


Figure 38. Angular Velocity vs Time of the Arm Segments for Subject 4.

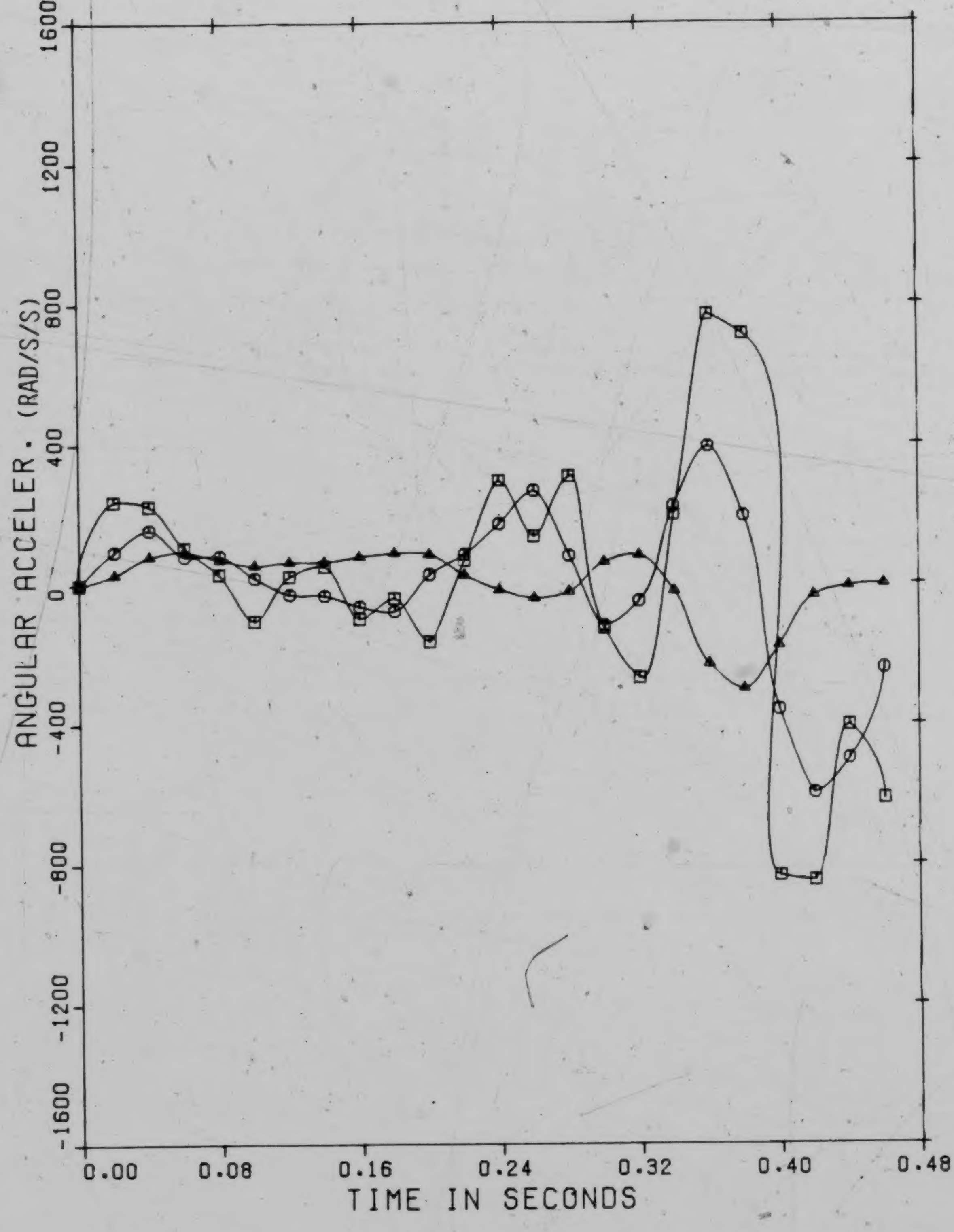


Figure 39. Angular Acceleration vs Time of the Arm Segments for Subject 4.

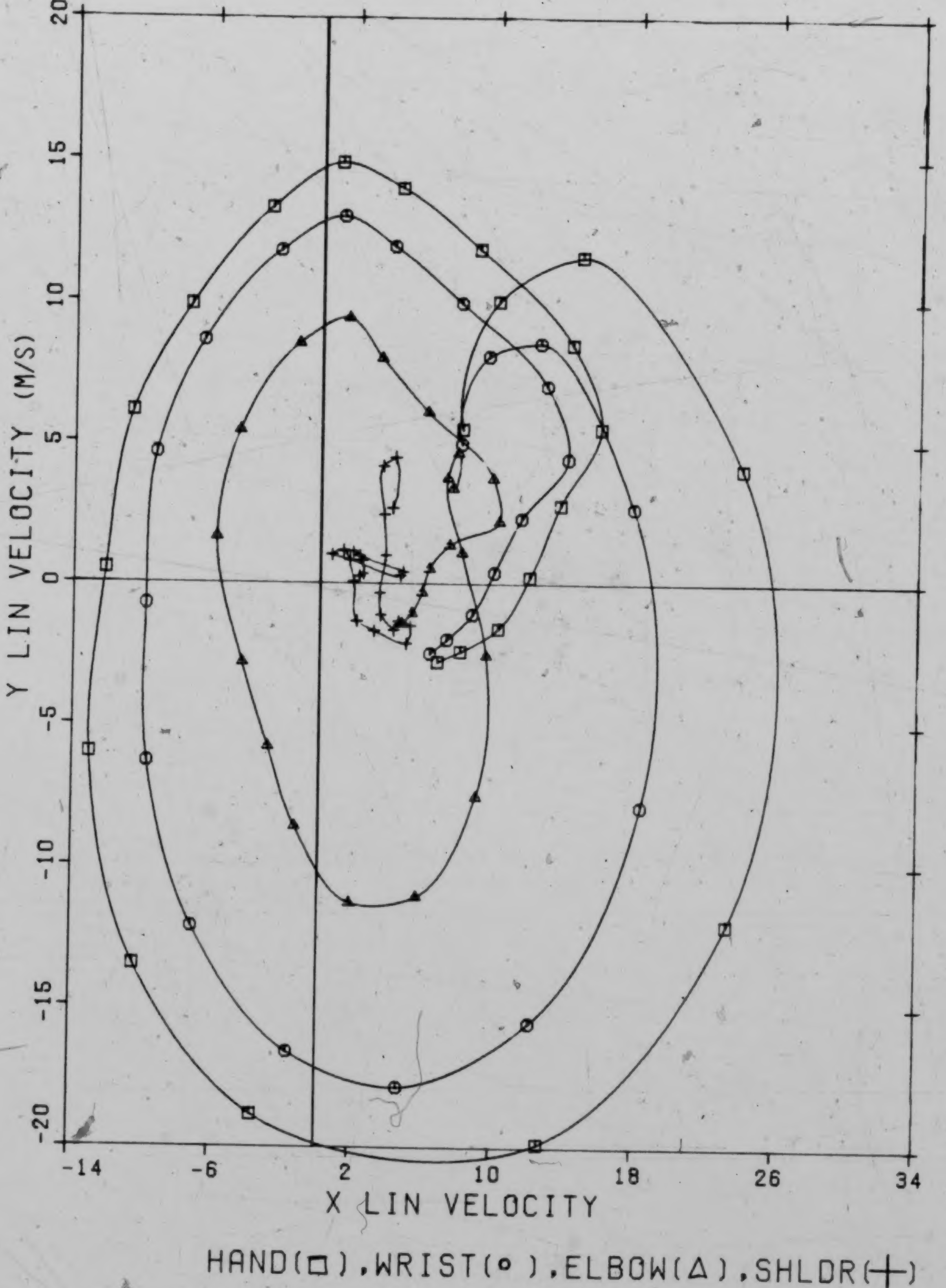


Figure 40. X and Y Linear Velocities of the Segmental Endpoints for Subject 4.

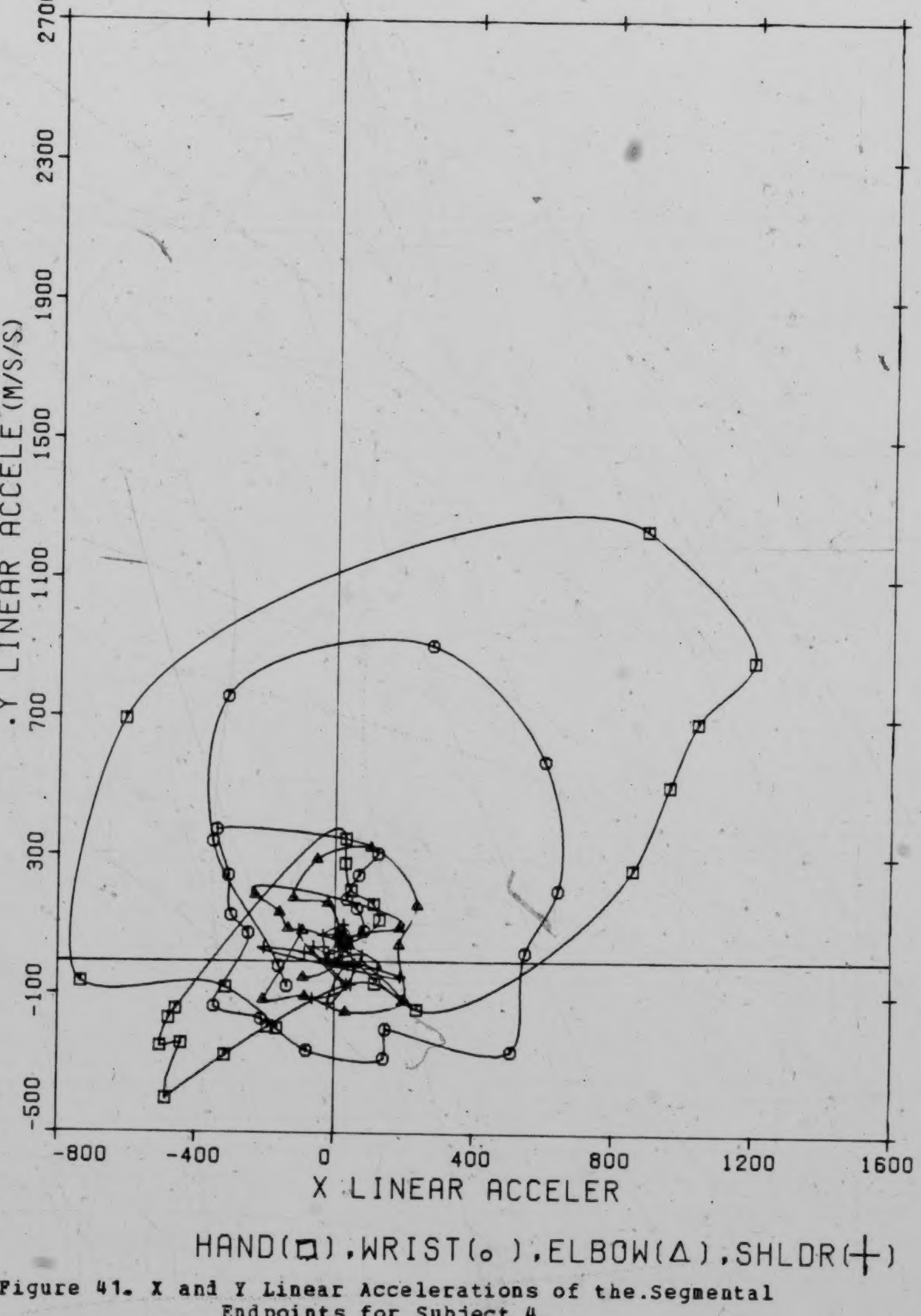


Figure 41. X and Y Linear Accelerations of the Segmental Endpoints for Subject 4.

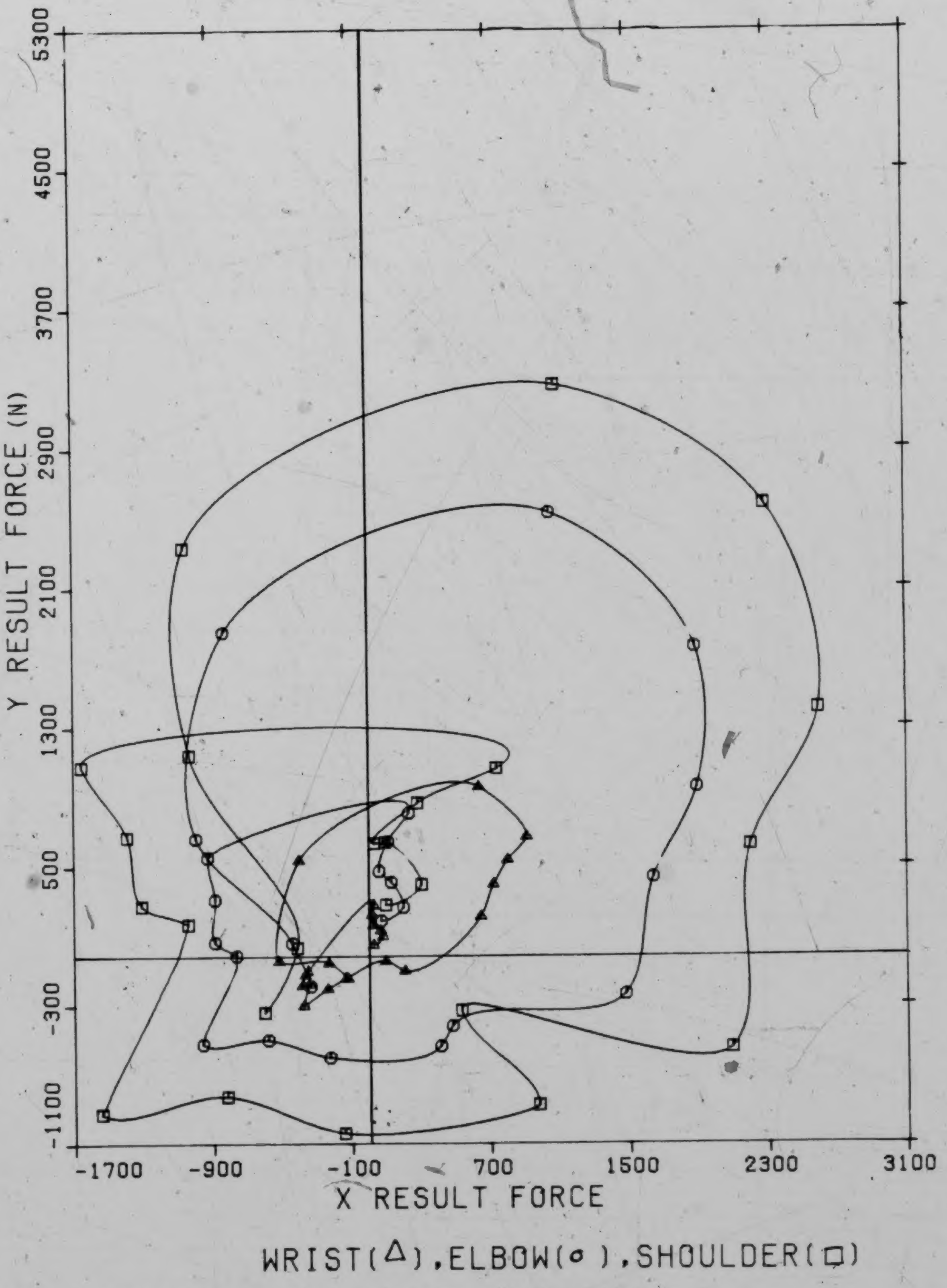


Figure 42. X and Y Joint Forces for Subject 4.

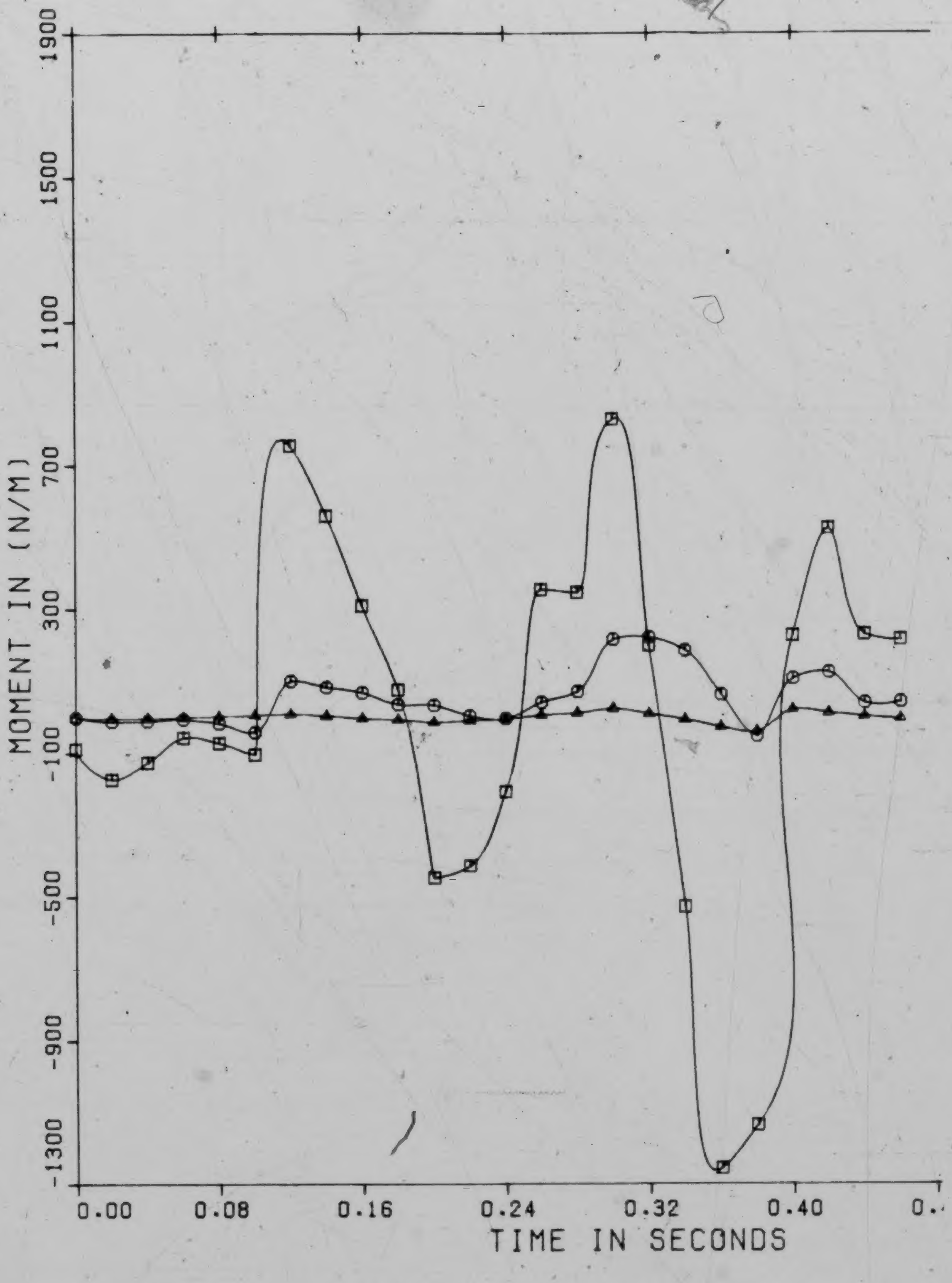
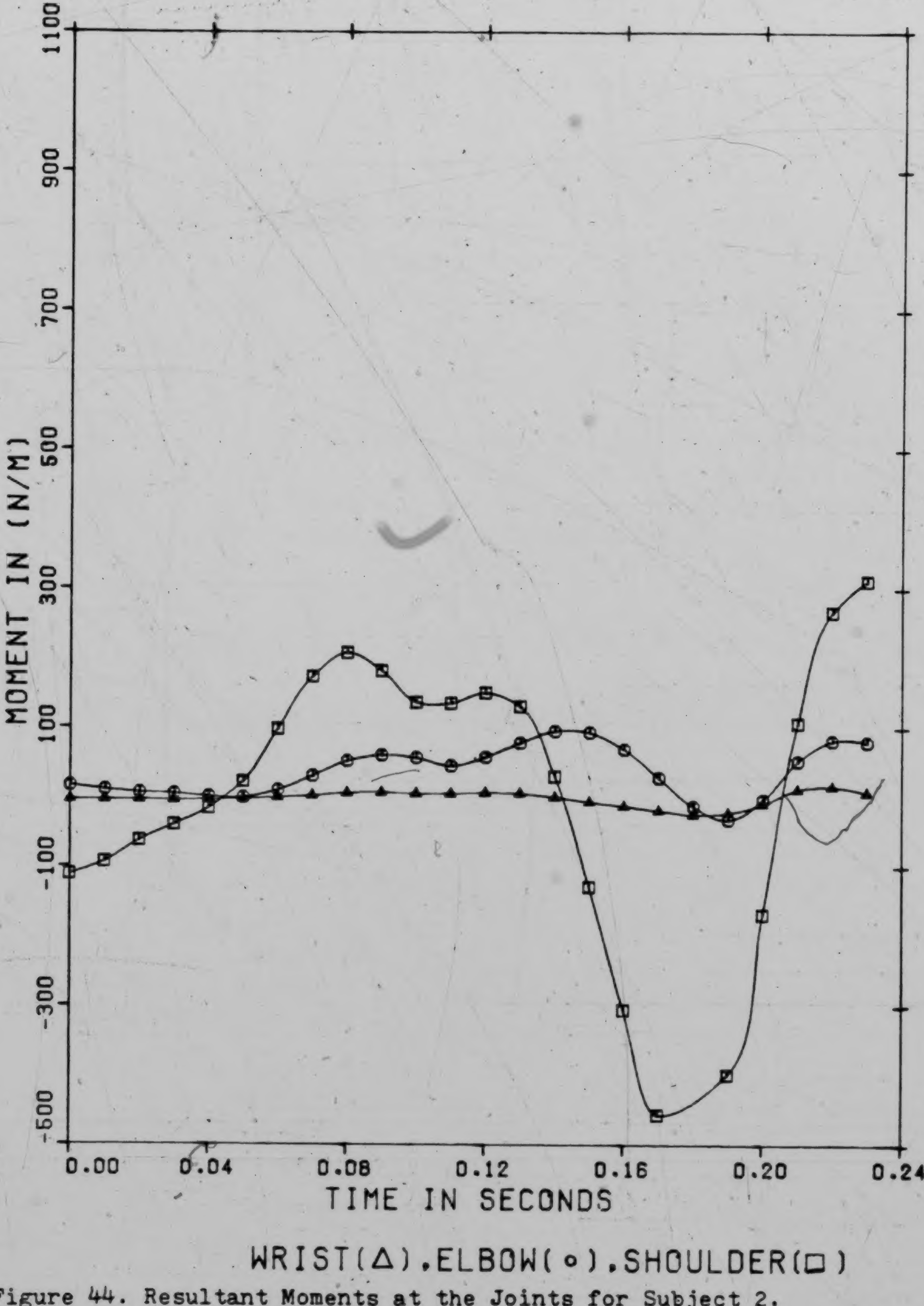


Figure 43. Resultant Moments at the Joints for Subject 4.



WRIST(Δ),ELBOW(○),SHOULDER(□)

Figure 44. Resultant Moments at the Joints for Subject 2.

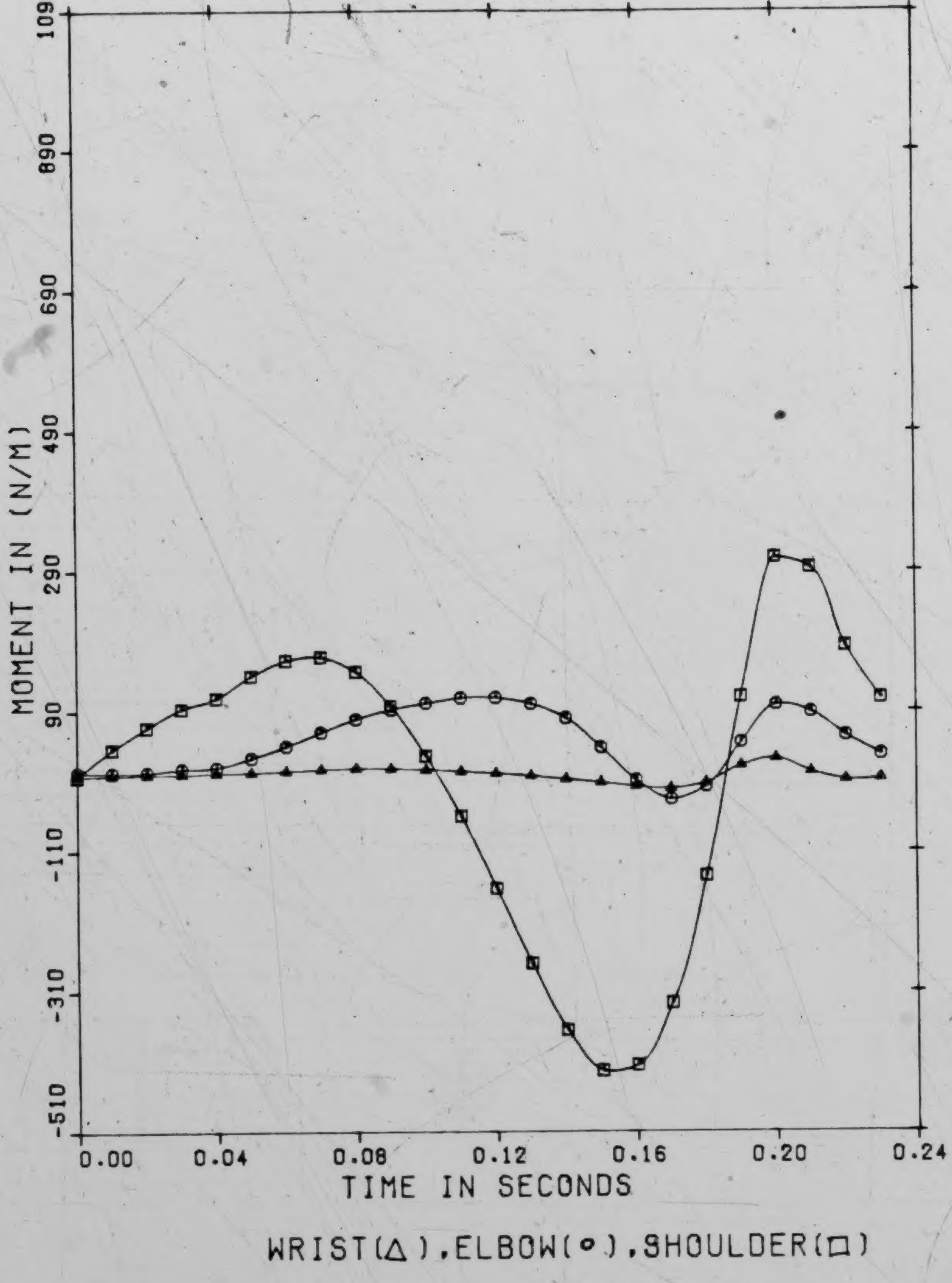


Figure 45. Resultant Moments at the Joints for Subject 3.

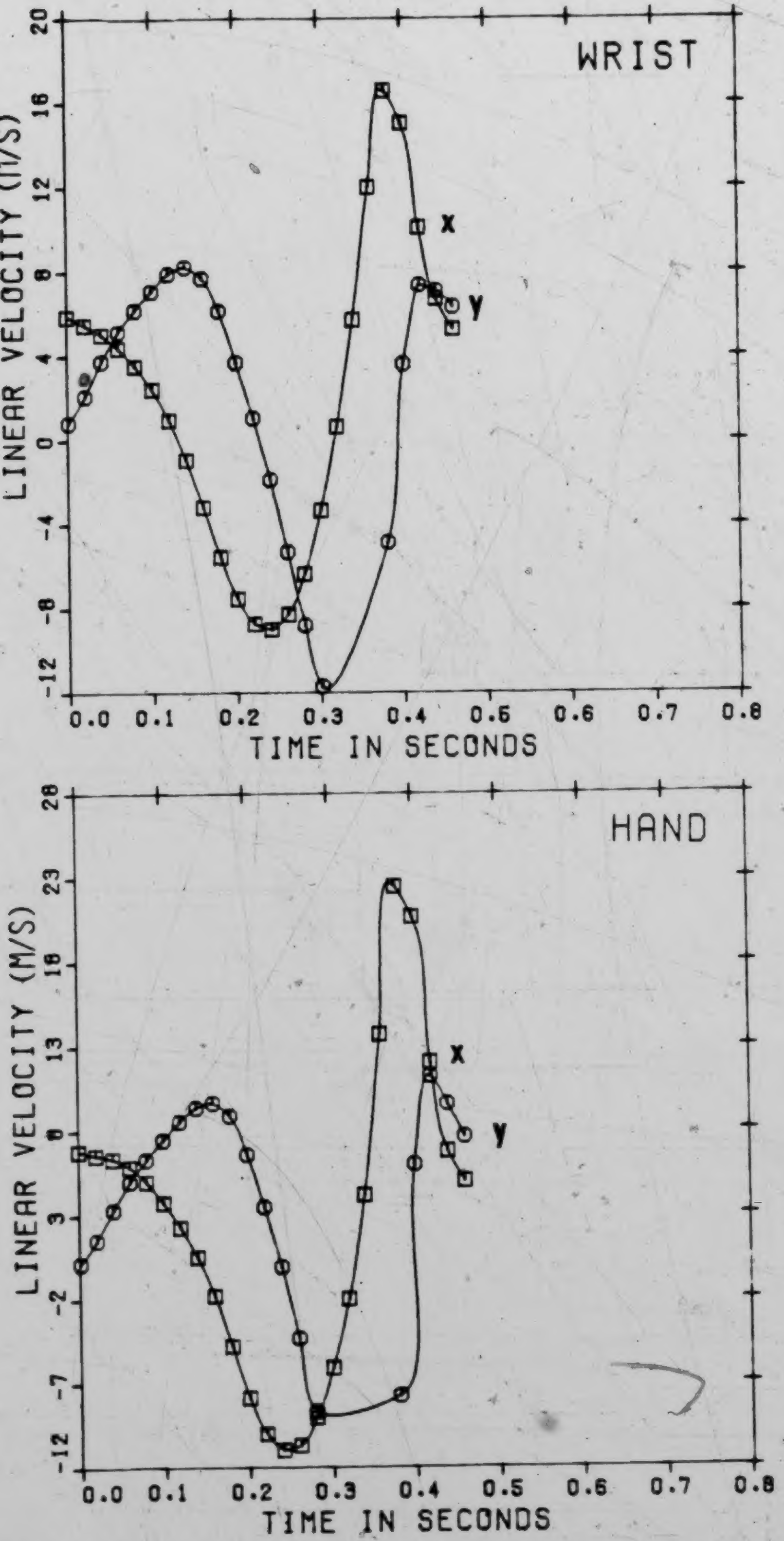


Figure 46. Hand and Wrist Linear Velocities for Subject 1.

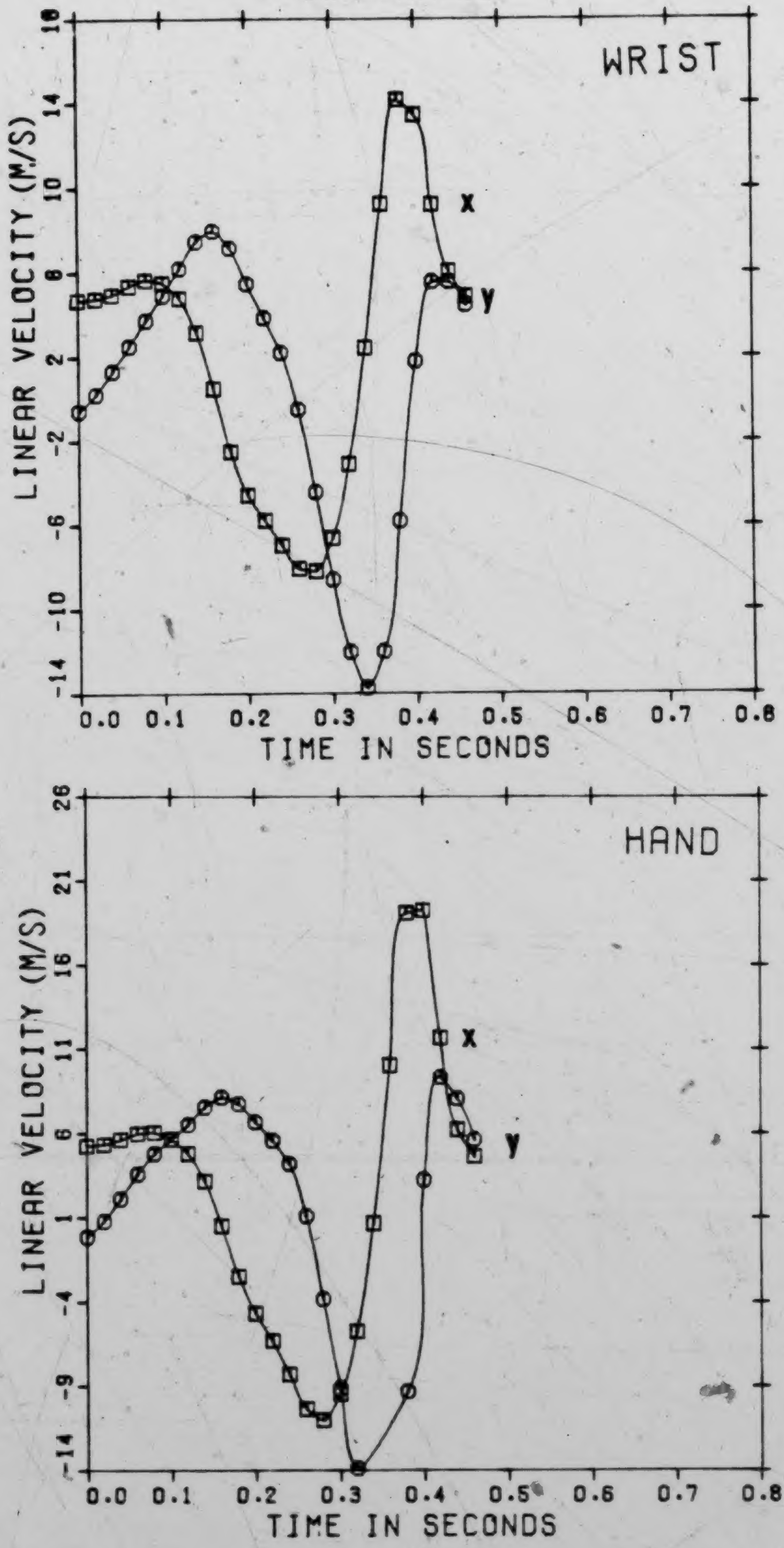


Figure 47. Hand and Wrist Linear Velocities for Subject 2.

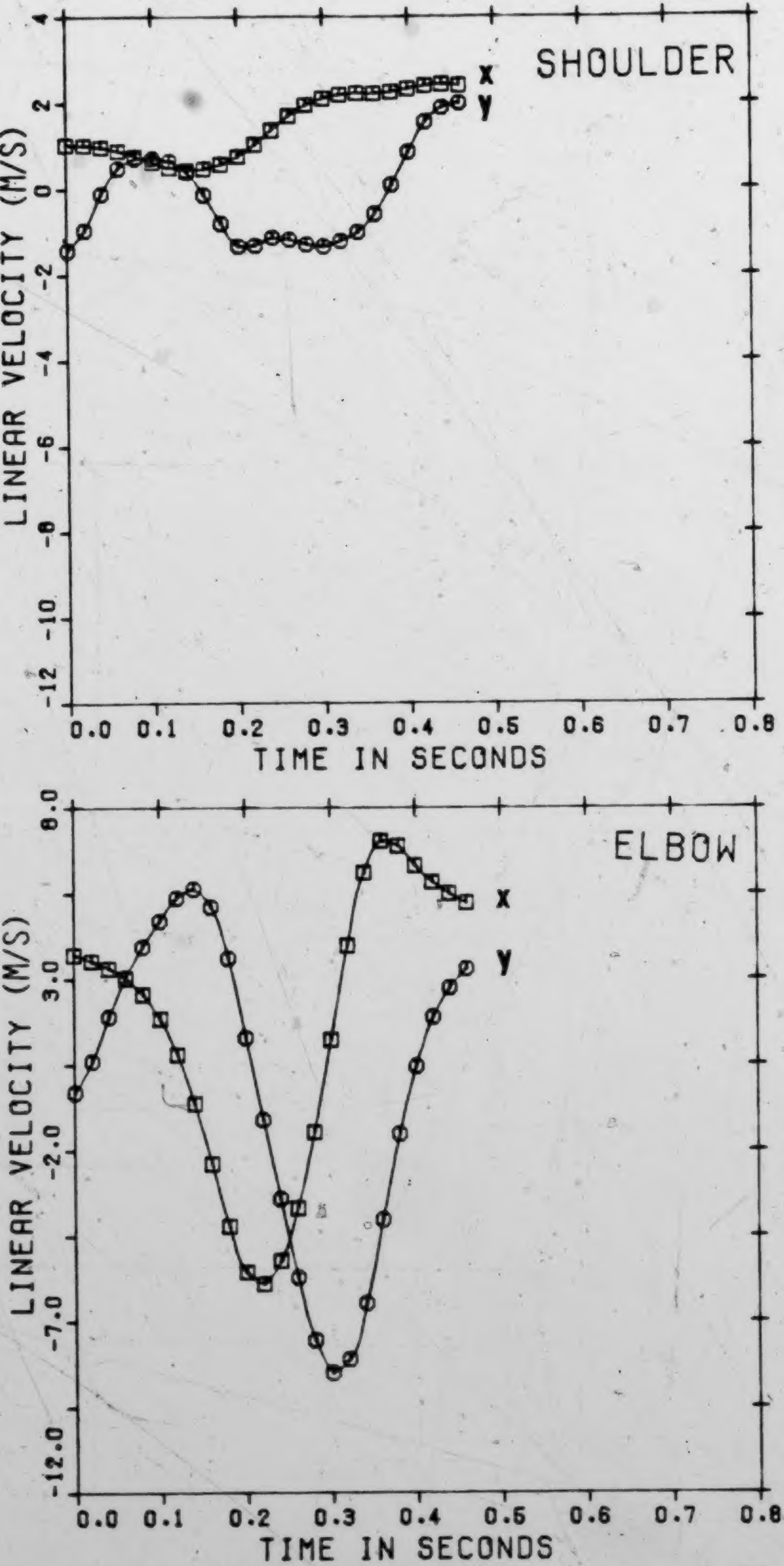


Figure 48. Elbow and Shoulder Linear Velocities for Subject 1.

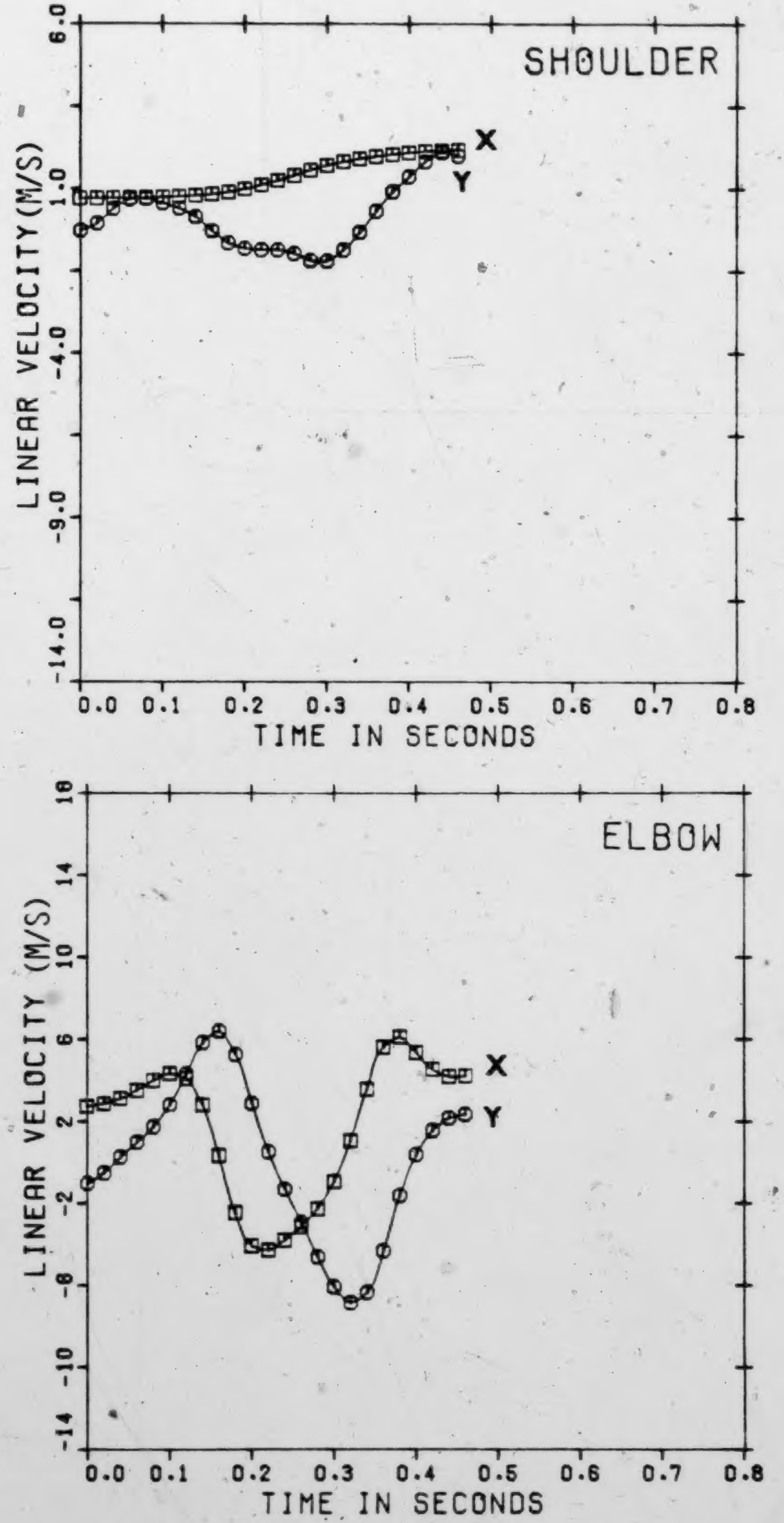


Figure 49. Elbow and Shoulder Linear Velocities for Subject 2.

displacement curves for the four pitches analyzed in detail, which were differentiated by the time scale along the abscissa. The marked similarily between these curves for any particular pitch was an indication of the reliability of the digitizing of the segmental endpoints; and the similarity between curves of different pitches was an indication of the similarity in technique between highly skilled performers. Since the curves produced for each pitch with different time scales were so similar, only one set of these curves are included here. Figures 9-16 and Figures 17-23 all represent the same pitch of subject 1, but digitized separately over a different time scale.

The curves for each of these angular displacements are very similar for each of the pitches analyzed in that all curves for each of the three segments exhibits an upward slope indicating an increasing angle when graphed against time. The wrist began at a lesser angle than the two proximal segments, which in this case was a larger negative number--all angles in this study were measured from the right horizontal. The two upper segments remained at almost the same angle for the first part of the wind-up motion, since the elbow joint was almost completely extended for the first .12 seconds of the motion. This resulted in the displacement curve which was characterized by nearly parallel lines for the proximal segments in the early part of the pitch. The curve for the hand segment inclination shows some variations during this time, which were likely due to the rotations which were occurring in the upper segments. Since these rotations were not measureable in a single plane, they were apparent only as they affected the position of the hand segment during the windup.

After the first .18 seconds of the windup, there was a shift in the relative positions of the segments--there was an increased flexion in the elbow joint so that the upper and lower arm segments no longer exhibited the same angular position. As these two displacement curves were moving further apart, the hand segment was altering its' position so that it came to lie at the same angle as the lower arm. This was apparent in the graphs of these curves, in that the lines for these two segments lie almost parallel and in close proximity up to the point of release of the ball, which occurs .40 seconds after the windup starts. At this point the curves for the hand and lower arm segments turn sharply upwards, and in fact the angles of both of these segments pass that of the upper arm segment, as indicated by the crossing of the three lines. These two curves continued to move upward at a rapid rate through the point of release and the early part ofthe follow through, at which time they were no longer parallel as their angles were changing in relation to the wrist.

The curve of the upper arm inclination was a flatter curve, as it moved upward at a relatively constant rate through release. It was notable that the maximum slope of the displacement curve for the upper arm motion was reached earlier that that for the two distal segments, indicating that there was a sequential nature to these movements. Pearson,et.al(1963) reported angular displacement-time curves similar to those reported in the present study, although the throwing skill analyzed in that study was only a modified shoulder flexion movement, not a ballistic throwing motion. Miller and Nelson(1973) also reported displacement-time curves for the leg segments during kicking, and these segments also exhibited the above pattern. Roberts and Metcalfe(1968) reported displacement-time curves of a kicking skill in which there are some opposing motions occurring in the leg segments. They noted that as the thigh segment moves forward to begin the kick, the leg segment is still moving backward, so that there is little net rotation of the leg segment at this point in the skill.

Angular Velocity

The angular velocity of each of the segments was also graphed against time for this skill. The most notable finding from the velocity graphs (Figures 10,17,24,31,38) is the timing of the peak velocities for each of the segments. In all the pitches studied in detail, the peak angular velocity for the upper arm segment was reached from .04 to .06 s earlier than that for the lower arm segment. As the peak velocity for the proximal segment was reached, the next segment (the lower arm) began to increase velocity rapidly, so that the velocities of each of the segments were added successively. The other notable finding was that the peak velocities of the lower arm and the hand segment occur at almost the same instant in time, or during the same .01 second interval between frames in this study. There was a slight difference in this finding between the four subjects tested. Subject 1 attained the peak angular velocities of these two segments .01 seconds apart (Figure 10), so that the lower arm segment attained this peak first. However, in the graph of Subject 1 over the longer time period (Figure 17), these two peaks appear to occur at the same instant, or over the same .02 second time interval. These peaks occur st time same time for subjects 2 and 4 (Figures 24,38), and subject 3 again exhibited an early peak of the lower arm segment (Figure 38). to the time of peak velocity of the upper arm segment. This finding is in agreement with that of Koniar(1971), who also noted that a skilled performer will reach maximum velocity of the segments at virtually the same instant. The angular velocity of the hand segment begins to increase sharply .04 seconds before release of the ball, so that it surpasses the angular velocity of the lower arm at a point just prior to release (.02 sec).

The shape of the velocity curve for the upper arm segment showed a gradual increase in velocity for the first .16 seconds of the pitch, at which time this segment maintained a rather constant velocity up to a point some .06 seconds before release. At this point, this velocity curve exhibited a sharp drop, indicating a rather rapid loss in angular velocity (Figure 10). This is a most interesting finding, in that it indicated that THE UPPER ARM SEGMENT ACTUALLY LOSES ANGULAR VELOCITY PRIOR TO RELEASE OF THE BALL, and in fact is in agrement with the findings of Plagenhoef(1966) who also noted that the proximal segments slow down prior to release of the ball in throwing skills. He stated: "The velocity of a given segment can be increased by decelerating the adjoining segment. (In whole body motions where a peak velocity is desired in the hands, the properly-timed stopping action of each segment in sequence from foot to hand produces the best results)(1966:110)." This finding is also in agreement with that of Roberts and Metcalfe(1968:316), when they stated: "When knee extension starts and accelerates, the leg gains speed. Meantime, the thigh begins to slow and almost stop....The thigh slows or stops before contact so that it is contributing little, in a kinematic sense, to foot speed at contact. Thus it seems reasonable to assume that it does make some active contribution to the speed of lower leg rotation."

This description raises interesting questions regarding the mechanisms of momentum transfer between segments of the body. It is likely that this slowing down of the proximal segments has a dual effect on the skill being performed. Firstly, there is likely a transfer of momentum effect from one segment to another, so that as the proximal segment is slowed down prior to release it's momentum is partially transferred to the distal segment. This transfer of momentum then serves to increase the angular velocity of this segment. Also the slowing of the proximal endpoint of the lower arm segment, which posesses a certain amount of angular momentum from previous movements, will cause the remainder of the segment to increase in angular velocity around this point due to this momentum. Another factor which may explain this segmental slowing was suggested by Roberts and Metcalfe(1968) as a neuromuscular mechanism. Since the distal segments trail the proximal segments for the first part of most ballistic movements due to the inertia of these segments, this puts the agonist muscle groups on a stretch. This stretch excites the muscle spindles and the joint receptors and causes a more forceful contraction of these muscles during the subsequent joint movements.

The curve of the elbow velocity exhibited a rather gradual increase in angular velocity for the first .20 seconds of the motion, at which point the elbow flexion occurred rapidly through the point of release. The curve which showed little smoothness was that for the velocity of the hand segment--there were two other notable peaks in the angular velocity of this segment prior to release. As was stated earlier, these irregularities are undoubtedly due to the rotations which were occurring in the two proximal segments around their longitudinal axes--since this analysis was carried out only in the X-Y plane, these rotations were not measurable even though they did have an effect on the position of the hand segment. It is notable, however, that although the velocity-time curve for the hand segment is quite irregular in shape, the same shape is apparent in all the graphs for this segment (Figures 17,24,31,38). All of these curves have three peaks, corresponding the three separate positions of this segment. The first peak occurs as the hand is being raised in front of the body during the first part of the windup--the rotation of the forearm causes an apparent change in this angle. The second peak occurs as the hand is being lowered from a position at the top of the backswing--as the arm is being flexed, the wrist becomes hyperextended and causes a relatively rapid change in the angle. The final peak occurs, as stated earlier, at the instant of release as the wrist is seen to exhibit rapid flexion, as viewed from the X-Y plane. Since this set of data was analyzed only in the X-Y plane, from the view of only one camera, the movement of the wrist appeared to be flexion. However, the movements of the tape markers on the arm segments indicated that these movements were actually rotations of the segments around their longitudinal axes, which could not be accurately quantified in this part of the analysis.

Angular Accelerations

The acceleration-time curves for the three segments of the upper extremity during the softball pitch show a more marked distance between their peak values than did the velocity curves (See Figures 11,18,25,32,39).; The peak acceleration for the upper arm segment is reached first, at a point .06 seconds prior to release of the ball; this is followed by the peak for the lower arm segment .05 seconds later, and then the peak acceleration of the hand segment occurred .01 sec prior to release of the ball. It is interesting that there is such a measurable lag between the peak accelerations of each of these segments, but as is apparent from the graphs the accelerations are added successively from the proximal to the more distal segments through release of the ball.

After each segment reached its' peak acceleration value, the curves dropped sharply, indicating a deceleration or loss of velocity. Otherwise, the curves for the two proximal segments are similar to those seen in the velocity-time curves; and once again the most marked deviations are seen in the graphs for the hand segment. However, because the process of differentiation magnifies any deviations in the data, the original slight deviations have become very large deviations in the acceleration curves--and those which have no real effect on the skill as it is being presently analyzed since they are due to rotations which were not measureable (Figures 25,32,39).

Another interesting point in the angular acceleration curves is the timing of the peak velocity in the skill compared to the timing of the peak accelerations. The acceleration peaks are reached first, and after the period of maximal acceleration has passed, the velocity curve reaches it's peak. At the time of these maximal velocities, then, the respective segments are already in a period of deceleration, as noted by the downward slopes of the acceleration curves. This is quite reasonable in terms of the attainment of maximal velocity on the ball at release, in that the segments should have all completed acceleration phases prior to this point in time.

Linear Kinematics

Linear Velocities

The linear velocities of each of the four segmental endpoints have been graphed with the X-linear velocities along the abscissa and the Y-linear velocities along the ordinate (See Figures 12,19,26,33,4 0). These four segmental endpoints are the shoulder, elbow, wrist and fingertips. This method of graphing linear velocity values enabled the investigator to report the X and Y velocity values on a single curve, and is one which has been used in several recent biomechanical investigations. (Pearson,et.al.,1963; Youm and Yoon, 1977) When the origin is clearly marked on a graph of this type, the resultant velocity vector at each point along the curve may be represented by the vector from the origin to that point. Thus the point in the pitch in which the velocity of any of the segmental endpoints is maximal is the point at which the distance of that curve from the origin is greatest. Since the linear velocities of the segmental endpoints increase from the proximal to the distal endpoints, the graph appears as a series of circular-shaped curves. The points at which these curves cross the X or Y axes are the points at which one of the velocity components are zero. The point of release of the ball, for example, is close to the point where the curves cross the right horizontal X-axis. At this point the Y-values are zero or minimal, and the X- values of the velocities are maximal. The largest magnitudes of the Y-velocities are negative, and occur at a point where the velocity curves cross the Y-axis, and the X-values are minimal. This point in the actual pitch occurs as the pitching arm is being forcefully flexed from the top of the backswing .

The curve representing the shoulder linear velocities has a characteristic shape unlike the graphs of of the other endpoints. This is of course due to the shoulder moving in a relatively constant path along with the whole body, while the other arm segments follow a circular path around this point in the windup motion for the pitch. In the curves in which the whole pitching motion is being represented, the curve is somewhat U-shaped due to the regular fluctuations of the Y- values of the linear velocity. From zero at the beginning of the pitch, the Y-values first rise during the early part of the delivery (.08 s), then these values drop for the next .18 s, and finally rise for the final part of the pitch. These Y- value fluctuations are due to the arm and body motions during the delivery of the ball. The values of the X-components of the linear velocity rise gradually as the delivery of the ball progresses to a point .20 s prior to release of the ball, at which point the X-values remain relatively constant through release. This results in a velocity curve which is almost a straight line parallel to the Y-axis, indicating a relatively constant X-value. (See Figures 26,33) The shoulder linear velocity values are a good estimate of the velocity of the body mass center, since their movements are very similar. It is possible that a high X-velocity of the body at release may contribute to the final velocity of the pitch--this would seem to be the case for Subject CM in the present study. Macmillan(1976) has noted that body velocity was not related to kicking foot velocity. This fact suggested that the true role of body velocity in skills of this type is to contribute to the direction of the ball, rather than to it's velocity.

The curves representing the elbow linear velocities (Figures 12,19,26,33,40) are smooth oval shaped curves, indicating regular and constant changes in these velocity components throughout this skill. The maximum X linear velocity values occur at a point .04 seconds prior to release of the ball, at which time there is also a rather large negative Y component of the velocity. The linear velocity curves for the wrist and fingertip velocity components are also smooth and regular oval-shaped curves, which differ from that of the elbow joint in that ther is a smaller Y velocity component at release. The maximal X values of these two curves are reached at a point where the Y- velocity is very close to zero.

Linear Accelerations

The X and Y components of the linear accelerations for each of the segmental endpoints have also been graphed on a single page for each pitch studied in detail (See Figures 13,20,27,34,41). These graphs are of the same type as those for the linear velocity values, in that their form is that of a series of concentric circle shaped curves representing each of the segmental endpoints. The smallest inner curve represents the linear acceleration values of the shoulder joint, and the curves go on in order to represent the more distal endpoints of the upper extremity. The largest outer curve therefore represents the X and Y acceleration values of the fingertips, which exhibit some irregularities which are undoubtedly due to the rotations of the arm segments during these motions.

The linear acceleration of the shoulder joint is represented by a curve which is almost a straight line. This indicated that the linear acceleration values of the shoulder joint were small compared to those of the other endpoints. The most notable point about the other three acceleration curves is the direction of the acceleration vectors for the various points on the curve. Because the linear acceleration values for each of these points was composed of both a normal and a tangential component , the directions of these vectors are different from the directions of the velocity or displacement vectors. For example, at release of the ball, the acceleration vector is found in the first quadrant of the graph, so that its' direction is over 45 degrees removed from the direction of the velocity vector for the same pitch. This finding is in agreement with that of Plagenhoef(1971) , who also noted that the resultant direction of accelerations are often quite different from that of the motion occurring. In the present skill, the direction of the velocity vector for the hand at release is in the direction of the path of the hand and ball. However, the direction of the acceleration vector is different from this, and is not pointing in the direction of the motion of the hand. It is also notable that for each of the segments, the acceleration vector becomes further removed from the direction of motion of the arm segments, as the segment becomes more distal. This is of course due to the fact that the acceleration is composed of a tangential component as well as a normal component which is calculated from angular velocity values. The more distal components have higher angular velocity values, and because the normal component is at right angles to the tangential component of the acceleration, these higher values will tend to pull the resultant further and further from the actual direction of motion of the segment.

Linear and Angular Kinetics

The accuracy of results from experiments of this nature were limited by two important factors: the validity of the anthropometric model used and the methods used to obtain acceleration from displacement-time data (Cavanagh and Gregor, 1975). Assuming that the anthropometric model used is valid for the subjects in the present study, the major problem may be that of the validity of the technique used to produce smoothed acceleration data from which the forces were calculated. However, recent investigators have stated that the cubic spline method of data smoothing produces the most accurate estimates of acceleration of body segments during sports' performances. (Zernicke, et.al., 1975; McLaughlin, et.al., 1976) These estimates are particularly critical in kinetic analyses using the force-mass-acceleration method of calculating forces at the joints and joint moments, as an incorrect estimate of acceleration values at a certain point in the skill will produce inaccurate force and joint couple values.

Resultant Forces at the Joints

With these limitations of kinetic analyses in mind, the graphs of the resultant forces at the joints are reported in Figures 14,21,28,35,42. Once again, the X and Y components of the joint forces at each of the three joints of the upper extremity have been plotted on a single graph, which is again formed of three concentric circles. The larger outer circle in these graphs is formed from the joint forces at the shoulder joint, which are greater in magnitude than those of the other two joints. The next curve represents the forces acting on the shoulder joint, and the final inner curve represents the forces acting on the wrist joint. This order is opposite to that seen in the earlier linear velocity and acceleratiomn curves, in that in these earlier curves the proximal segments were found represented by the inner circles. The reason for this change in the order of representation of the segmental endpoints is that in this kinetic analysis we are now concerned with the product of the mass and the acceleration. Because the proximal segments have a considerably greater mass than the distal ones, the resultant joint forces are also larger for these segments.

It is notable that once again the resultant force vector acting at each of the joints is acting in a direction approximately 90 degrees to the direction of the velocity vectors at these joints, similar to that described earlier for the acceleration curves. As Plagenhoef stated: "Each body segment has a normal and tangential acceleration that produces unpredictable force directions---A slow moving but greatly accelerating segment can have a force direction almost 90 degrees different than if that segment were moving at a uniform velocity (1966:110)". For example, the resultant velocity vector at release for the wrist for subject 1 was calculated to be approximately 90 degrees from the direction of the resultant force vector for this same joint. This is once again due to the fact that there are two components in the acceleration acting at right angles to one another. Otherwise the force curves are relativly symmetrical for each of the joints. All three of these force curves begin in the fourth quadrant with both X and Y components being negative. This indicated that the initial forces at all three joints point downward and backward (Figures 14,21,28,35,42). The X force then becomes positive, indicating that the force at the joint is now in a forward direction. The Y component of the joint force remains negative for the first .10 s, at which point the Y joint force is reversed and becomes positive--ie. the vector points upward. The forces at the shoulder joint have the largest magnitude, while those at the wrist joint are the smallest, once again due to the greater inertia of the segments of the whole arm.

Resultant Moments at the Joints

The graphs of the resultant moments at the joints are reported in Figures 15,22,29,36,43,44,45 and the calculated values from which these graphs have been drawn are reported in Appendix G, Raw Data. These curves have been drawn so that a positive value of the curve represents an anticlockwise, or flexion moment at the joint; and a negative value of the curve represents an extension moment at the joint. The most marked curve in each of these graphs is the large negative moment which represents the slowing down, or reversal of movement of the upper extremity around the shoulder joint prior to the time of release. This large negative moment occurs at a point .03 to .04 seconds prior to release of the ball, and is closely followed by a large positive moment at the elbow and wrist joints which is representative of their period of rapid flexion prior to release. The moments at the wrist joint are really quite minimal, as can be seen from these figures.

Plagenhoef(1971:40) has stated that: "The magnitude of the moments of force indicates the extent of muscle contraction,--because the eye cannot perceive the change from acceleration to deceleration, nor calculate the effect of gravity relative to the speed of motion, it is also evident that muscle action cannot be determined visually for a simple segment motion except in a very general way." In terms of the muscle action accompanying these moments at the joints of the upper extremity, the large negative moment at the shoulder joint can only be produced by the action of the extensor muscles of the shoulder, causing a reversal, or slowing down of this motion. It is therefore likely that the shoulder flexors (pectoralis major, anterior deltiod,long head of biceps) are most active relatively early in the action, and this activity is reversed .06 seconds prior to release. It is at this point that the shoulder extensors come strongly into the action to reverse the moment at the shoulder joint and cause slowing down of this segment. This slowing down of the proximal segment then facilitates the rotation of the distal segment, since it's relative rotation is greater when the proximal endpoint is stopped or slowed down. As Ariel(1974:75) has noted, muscle action at one joint can produce muscle action at an adjoining joint just opposite to that indicated by the movement. "The moments indicate the dominant muscle forces and the effect of one segment on the adjoining segment. In any human performance, one segment may affect the adjoining segment in a manner which is undetectable by the human eye. At times, the moments of one segment are so large that they will be the dominating muscle force at the next segment---" (1974:75).

In the moment curves reported in Figures 15,22,29,36,43,44,45,, the large negative moment at the shoulder joint produced an accompanying negative moment at the elbow and wrist joints, even though both these joints are flexing at that point in the pitch. This indicated that the dominant muscle group at release of the ball was the shoulder extensors which were acting eccentrically as a brake to slow down the flexion of the upper arm at the shoulder joint. This is a most interesting finding in light of the fact that the major force producing muscles in this skill were thought to act strongly up to the point of release. These findings indicate that an electromyographic analysis of the active muscles during the softball pitch would be interesting to compare with the moment analysis. It would appear possible from the present analysis that the most important muscle forces in this skill may not be those of the agonist muscles to these movements, but rather those ofthe antagonists. Possibly in training highly skilled pitchers in the future, we should be training the shoulder extensors to act as a strong brake to this action, rather than to work for a more forceful agonist contraction.

Three Dimensional Analysis

From the digitized film data from the two cameras, it was possible to produce spatial coordinates for each of the segmental endpoints of interest for the pitches of two of the subjects. These spatial coordinates for five segmental endpoints for sixty frames of film are reported in Appendix F. The mathematical probability of the value of each of the computed points being correct is also reported in Appendix F. It should be noted that a number of these computed points have very low probabilities, which are likely due to one of the following sources of error: 1. The error accompanying the digitizing of any points from film data due to location of joint centers especially when the point of interest is not in the camera view as when being hidden by another body part. 2. It was found that many of the digitized data points had been incorrectly altered in the transmission process from the HP cassette tapes to the Ahmdal computer. These were corrected as well as possible, but some of these transmission errors may have escaped detection. 3. The digitizing board is only calibrated to .01 inch, so that the significant digits were limited to two. 4. On several occasions, one of the frames of data stored on the cassette tape could not be read back, so that both files had to be corrected for this error. 5. The most critical problem was in the synchronization of the frames of each film of this skill. The frames were slightly out of phase with one another, so that even though the frame rates were the same, it was not possible to digitize the points at exactly the same instant in time. However, notwithstanding these errors, the X,Y, and Z coordinates for each of the segmental endpoints of the arm and the ball were calculated over sixty frames of the pitch. Each of these points were then read into a computer program written by the author, in which the X,Y, and Z displacement, velocity and acceleration values were calculated for these points. This procedure was carried out for the best pitch of two of the subjects. Although the raw data was available for the other two subjects, these spatial coordinates were not calculated due to the expense of running the computer program.

The velocity graphs of the spatial coordinates of the shoulder and elbow point are quite similar for each of the subjects (Figures 54,55,56,57). The alternating peaks of the X and Y velocity values of the elbow are characteristic of this skill due to the circular motion of the arm. The velocity curves of the shoulder show little deviation, with the Y component exhibiting the greatest range. The Z component of these velocity curves has a characteristic

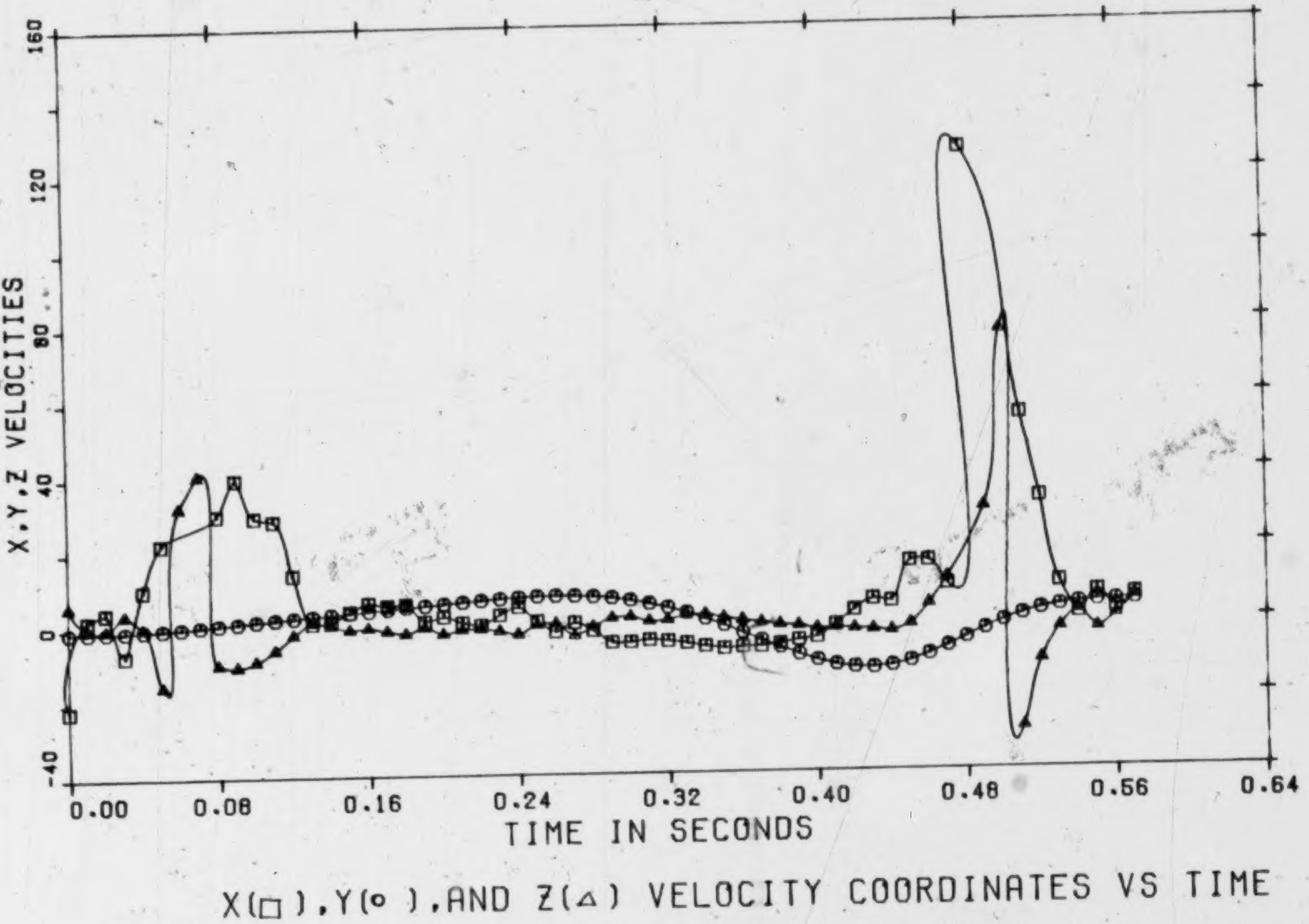


Figure 50. X, Y, Z Linear Velocities of Hand for Subject 1.

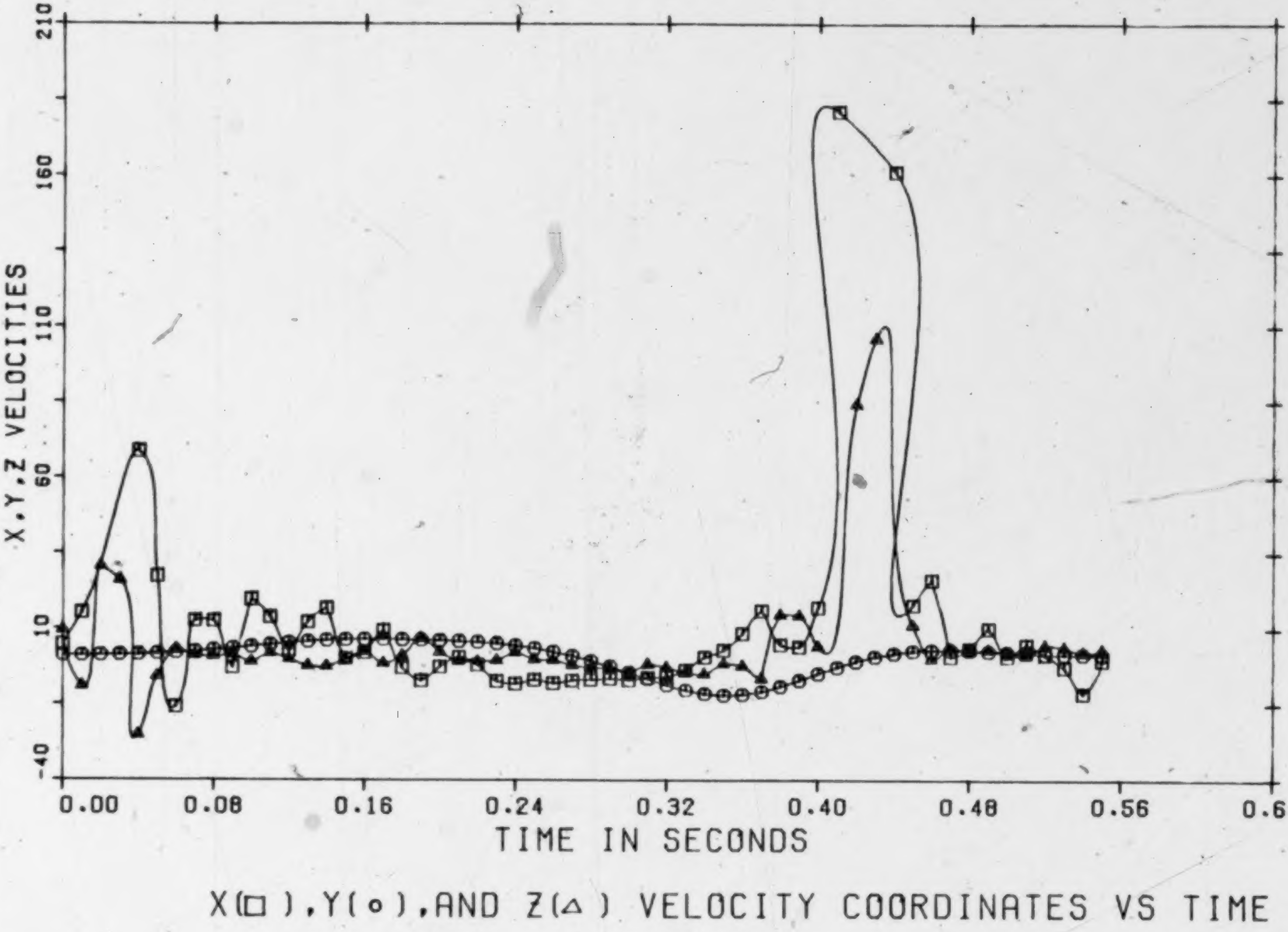


Figure 51. X, Y, Z Linear Velocitie's of Hand for Subject 2.

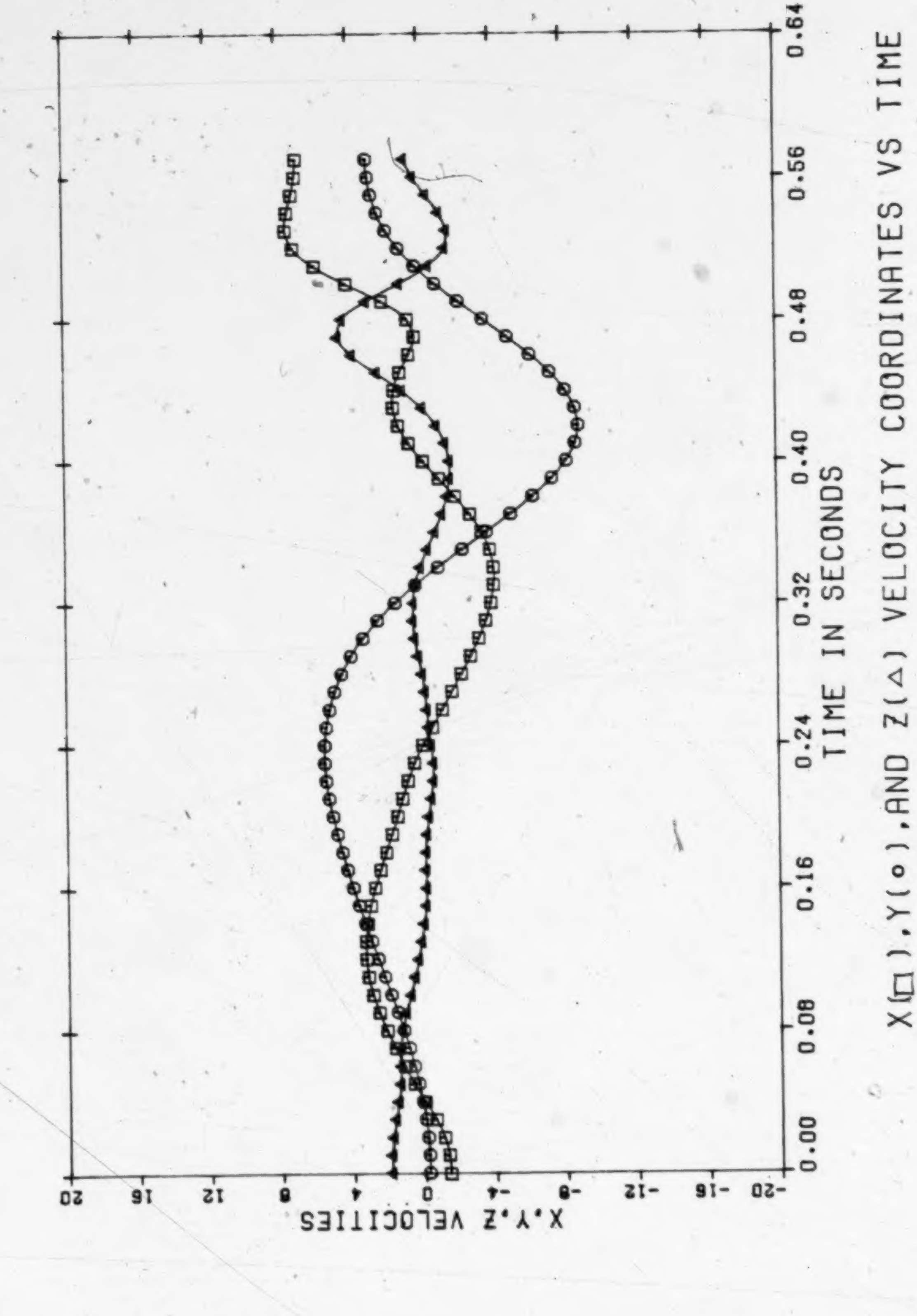


Figure 52. X, Y, Z Linear Velocities of Wrist for Subject K

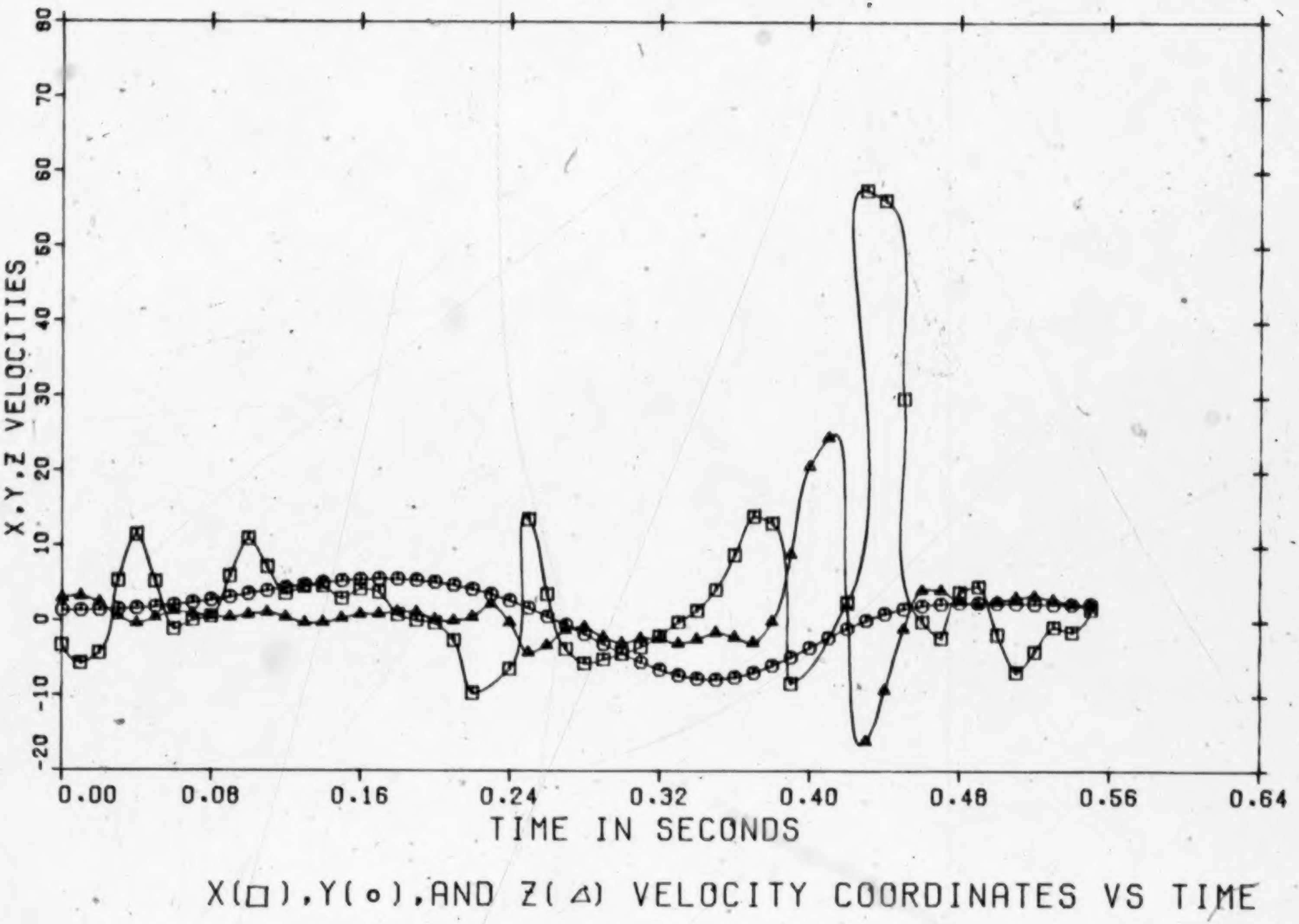


Figure 53. X, Y, Z Linear Velocities of Wrist for Subject 2.

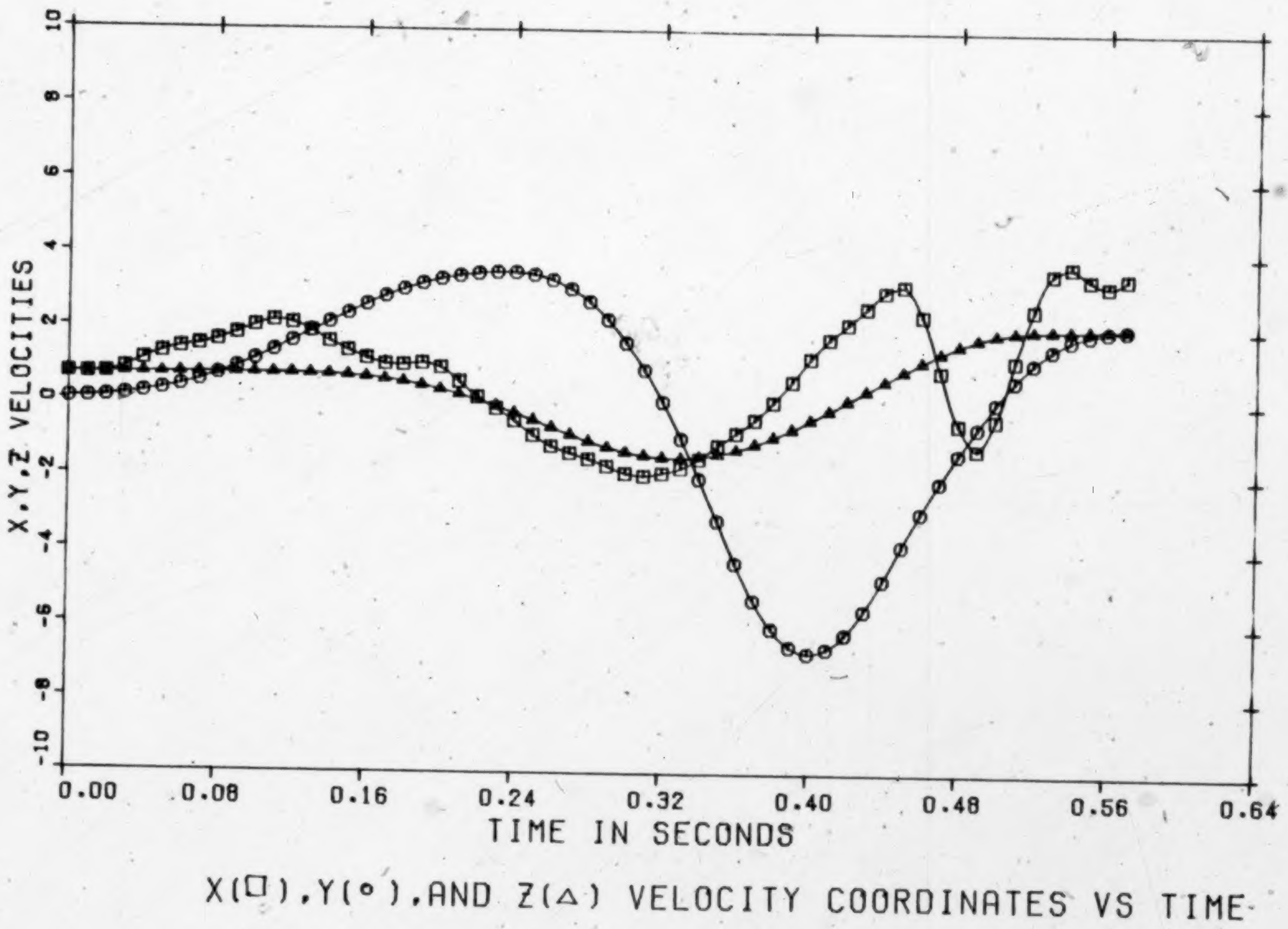
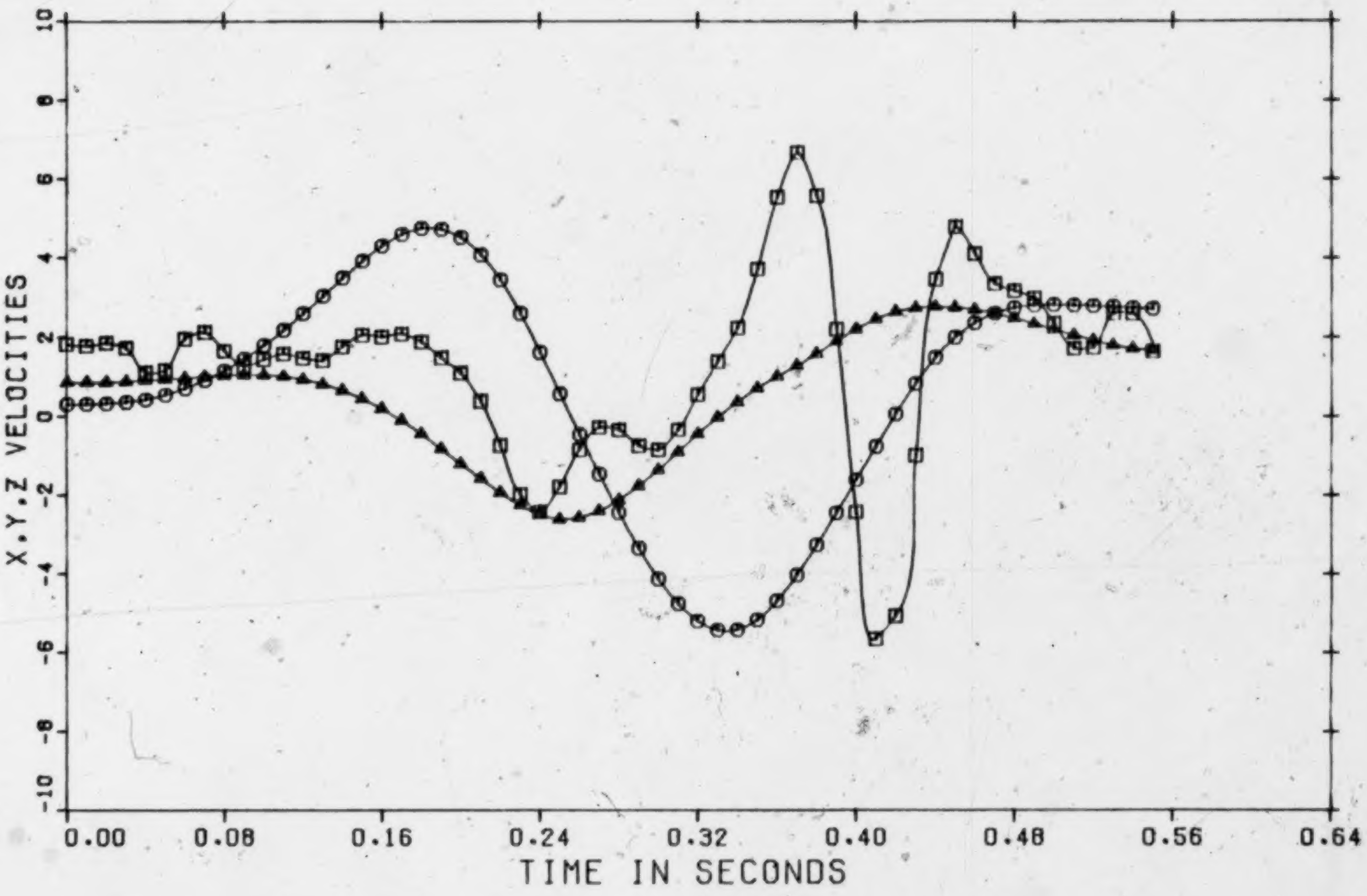
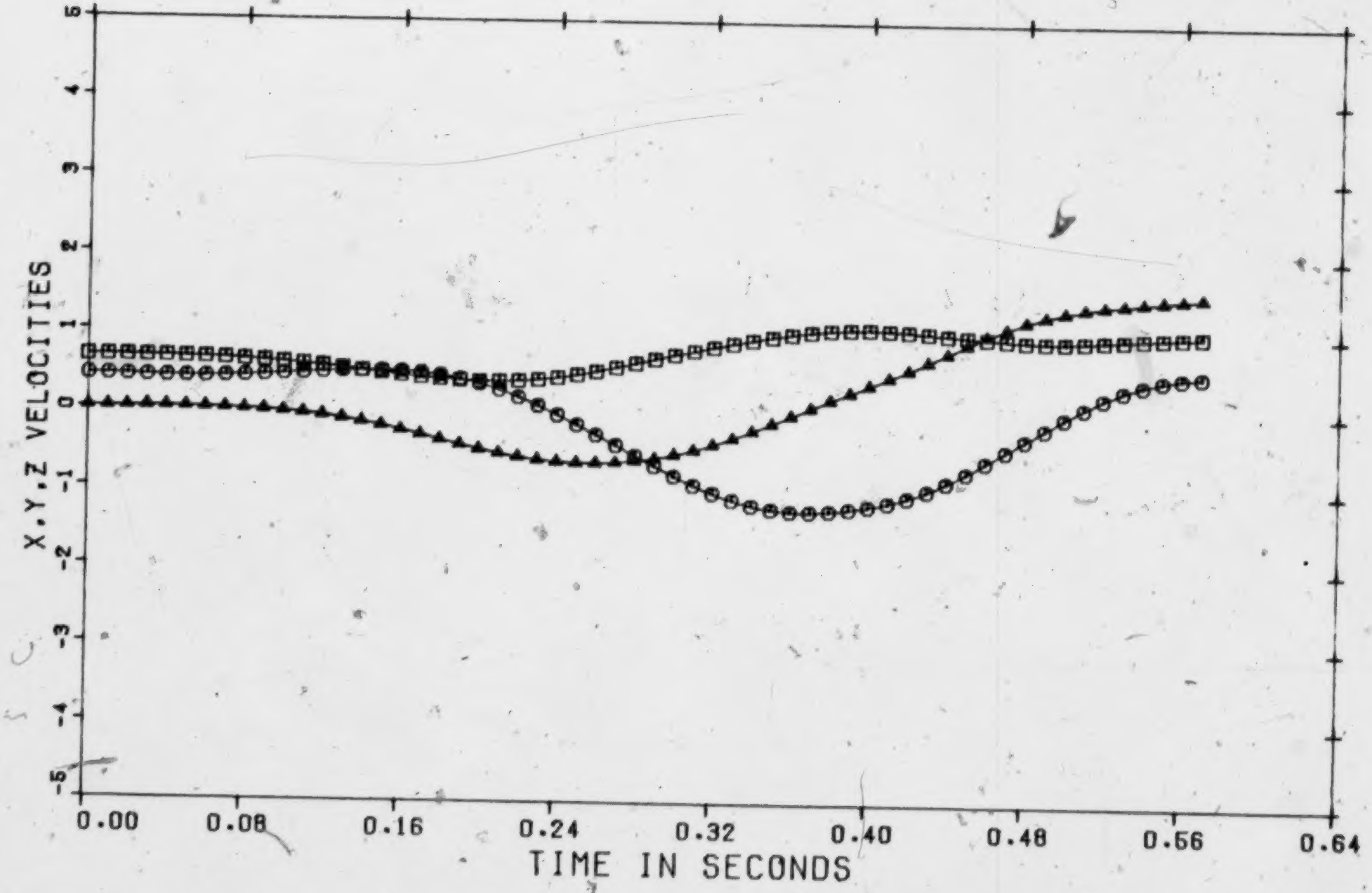


Figure 54. X, Y, Z Linear Velocities of Elbow for Subject 1.



X(□),Y(○),AND Z(△) VELOCITY COORDINATES VS TIME

Figure 55. X, Y, Z Linear Velocities of Elbow for Subject 2.



X(□),Y(○),AND Z(△) VELOCITY COORDINATES VS TIME

Figure 56. X, Y, Z Linear Velocities of Shoulder for Subject 1.

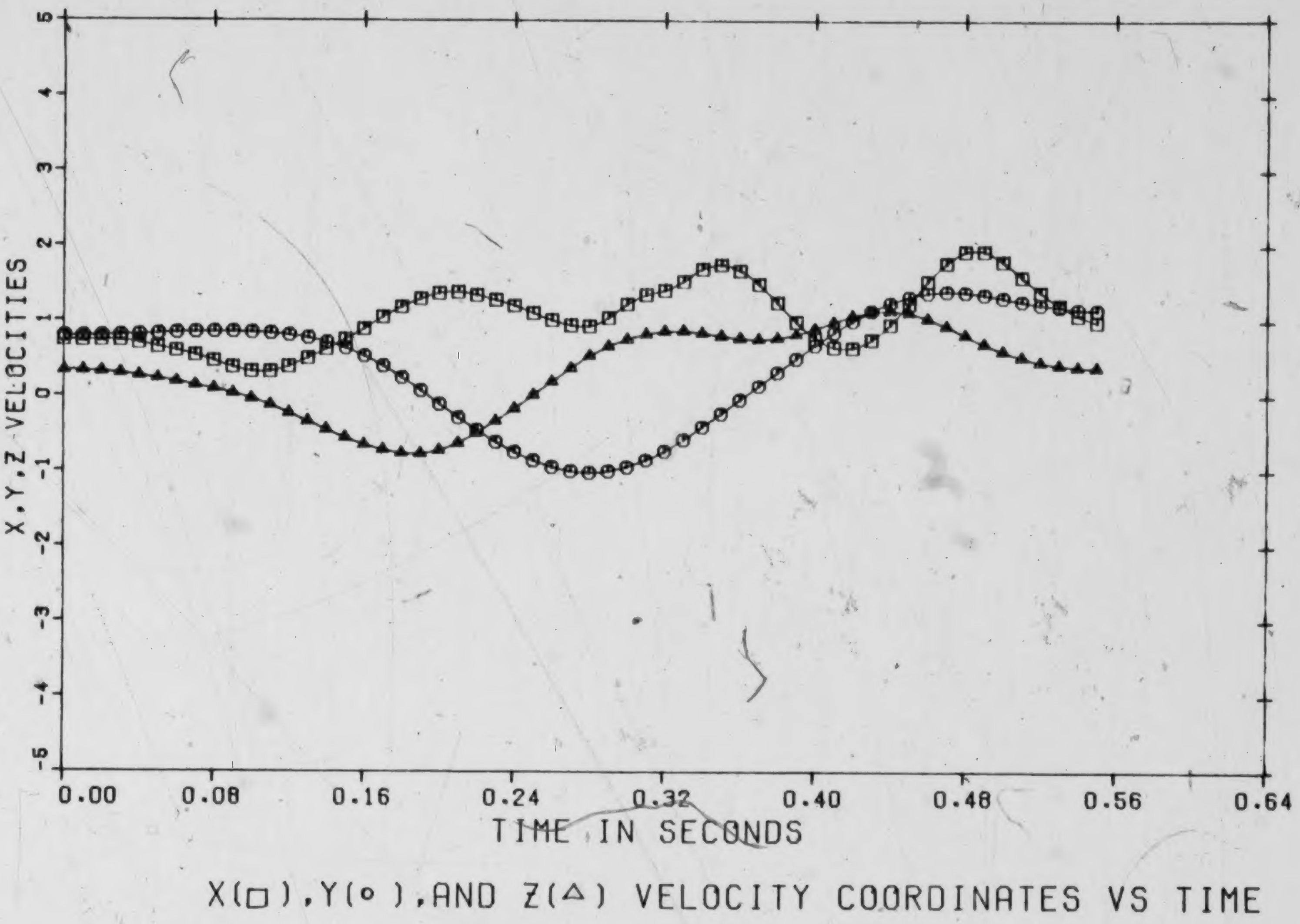


Figure 57. X, Y, Z Linear Velocities of Shoulder for Subject 2.

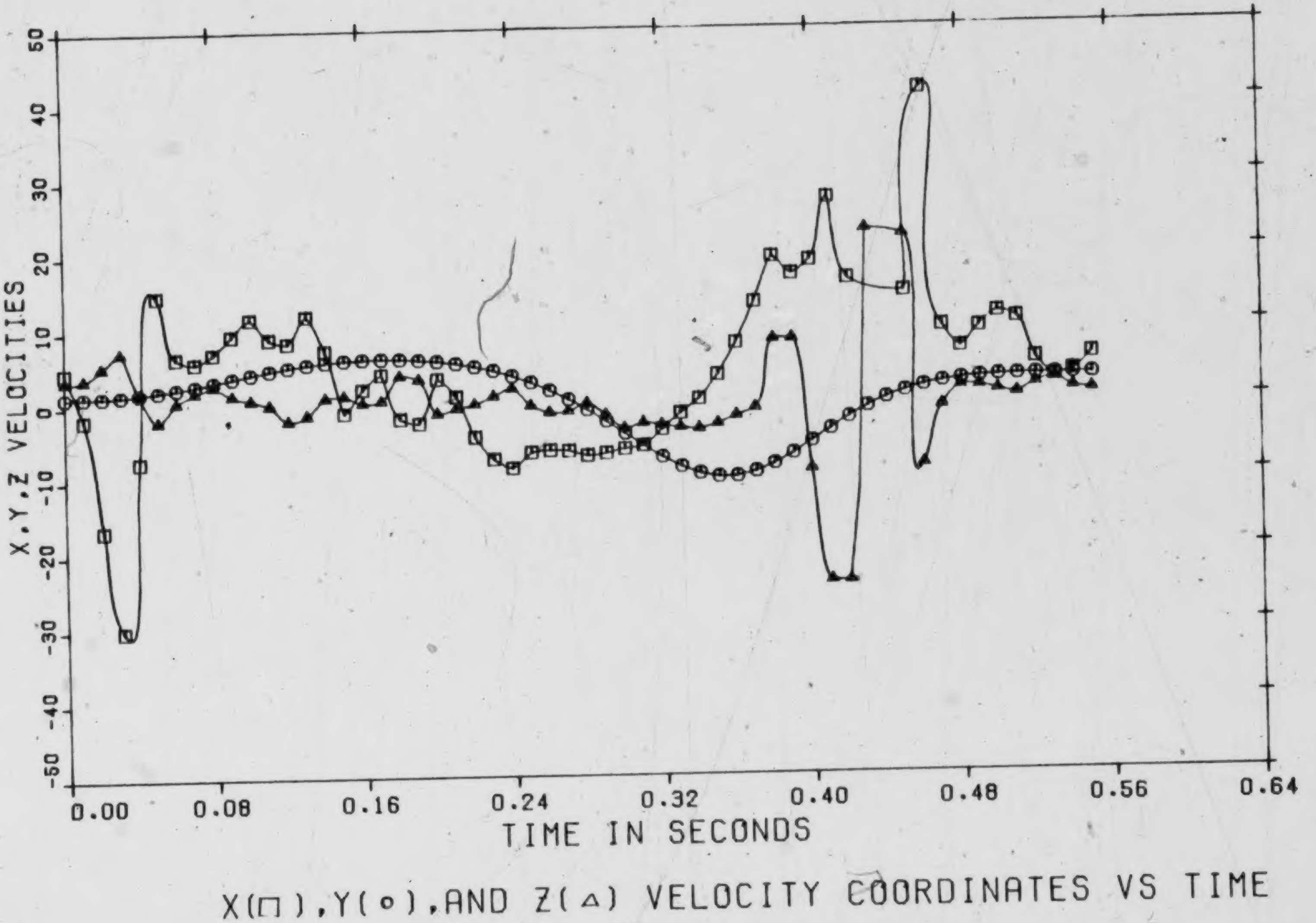


Figure 58. X, Y, Z Linear Velocities of Ball for Subject 1.

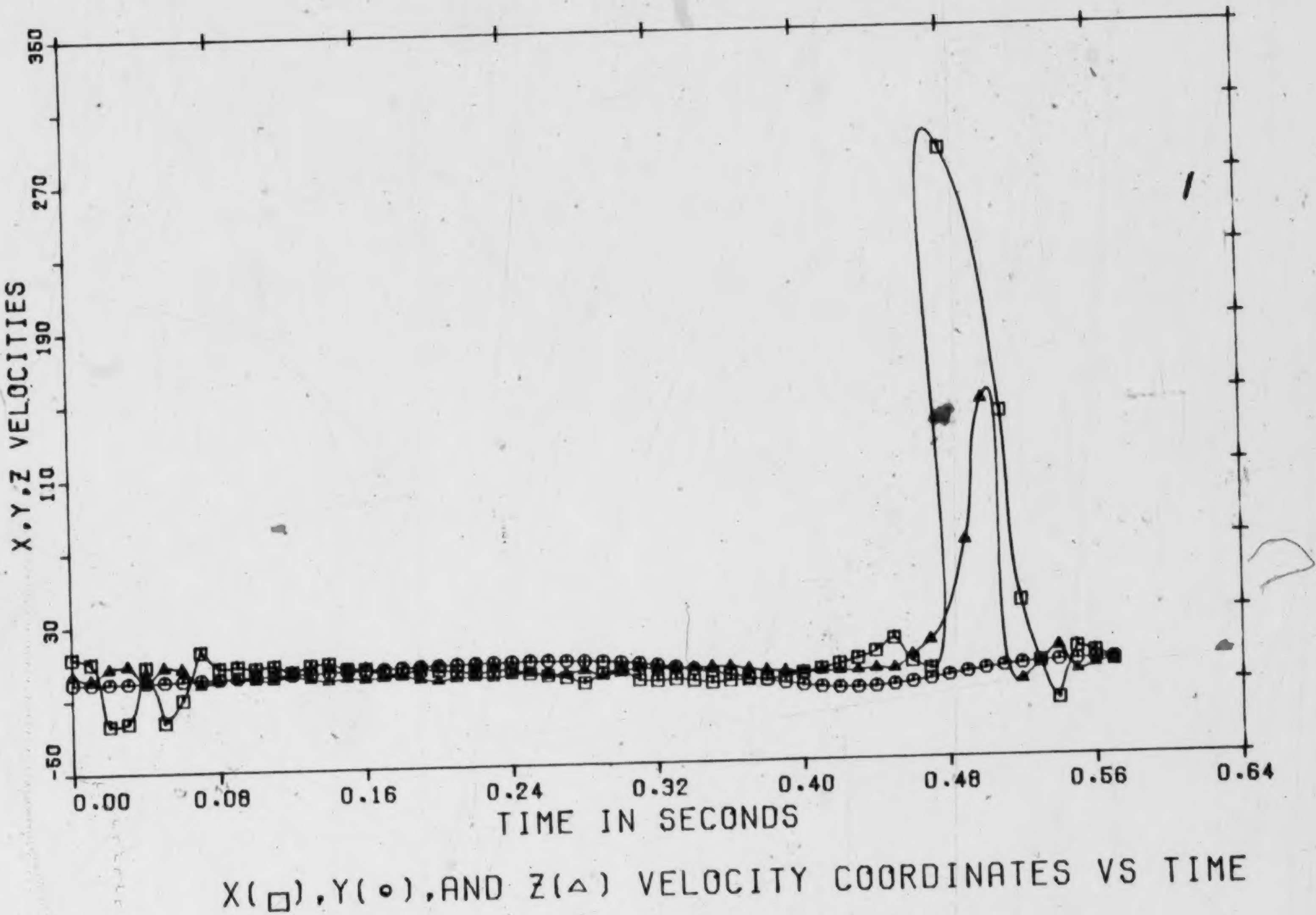


Figure 59. X, Y, Z Linear Velocities of Ball for Subject 2.

shape for these two endpoints, consisting of a slight rise early in the pitch (increased velocity laterally from the pitcher), followed by a drop .10-.12s prior to release and then a rise into release of the ball. This curve indicates that these endpoints are moving laterally during the actual release of the ball, likely a reaction from the body rotation in the opposite direction to keep the arm moving in a relatively straight line. These curves for the elbow and shoulder joints were found to be similar to those produced from the planar analysis (Figures 48,49).

The curves of the three component velocities for the hand,wrist and ball (Figures 50,51,52,53) are open to question, as they do not exhibit a marked similarity to the curves of these same points in the planar analysis (Figures 46,47). They are generally accurate, in that there is a peak in the X-velocities for these points at the time of release of the ball. The curve of the Y component of the velocities exhibited the same general shape throughout these graphs. However, there are numerous eratic data points which make the velocity curves appear rough, which are likely due to the difficulty in exact synchronization of the films. The graphs of the larger endpoints, which did not move as much between frames, were reasonably consistent. The smaller endpoints showed up more of the error incurred in having each frame slightly out of phase. However, these graphs are useful in illustrating some of the major velocity changes in these points, and in the timing of the peaks of these values. Probably the most useful outcome of the three-dimensional analysis was to provide a means of producing spatial coordinates of a high velocity ballistic movement, which had not been done in any other studies located by the author.

Three Dimensional Angular Velocities

The results of the angular velocity calculations for the lower arm segment are reported in Figures 60,61. Although these values provide reasonable estimates of these angular velocity values, some of the points were not as accurately located as would have been desirable. The determination of these angular velocity values required that there were three non colinear points visible on the segment of interest for all frames analyzed. However, for several of the frames analysed, one or more of these points of the lower arm segment were not visible from one of the cameras. This was due to the rotations occurring in this segment during the skill, which were unavoidable. In future analyses of this type it would be more accurate if numerous point markers were placed on the arm segment, so that any two of these markers which were visible to both cameras could be used. A further source of error in this analysis is the problem of inability to exactly synchronize the frames from each of the cameras.

The magnitudes of the computed angular velocities for

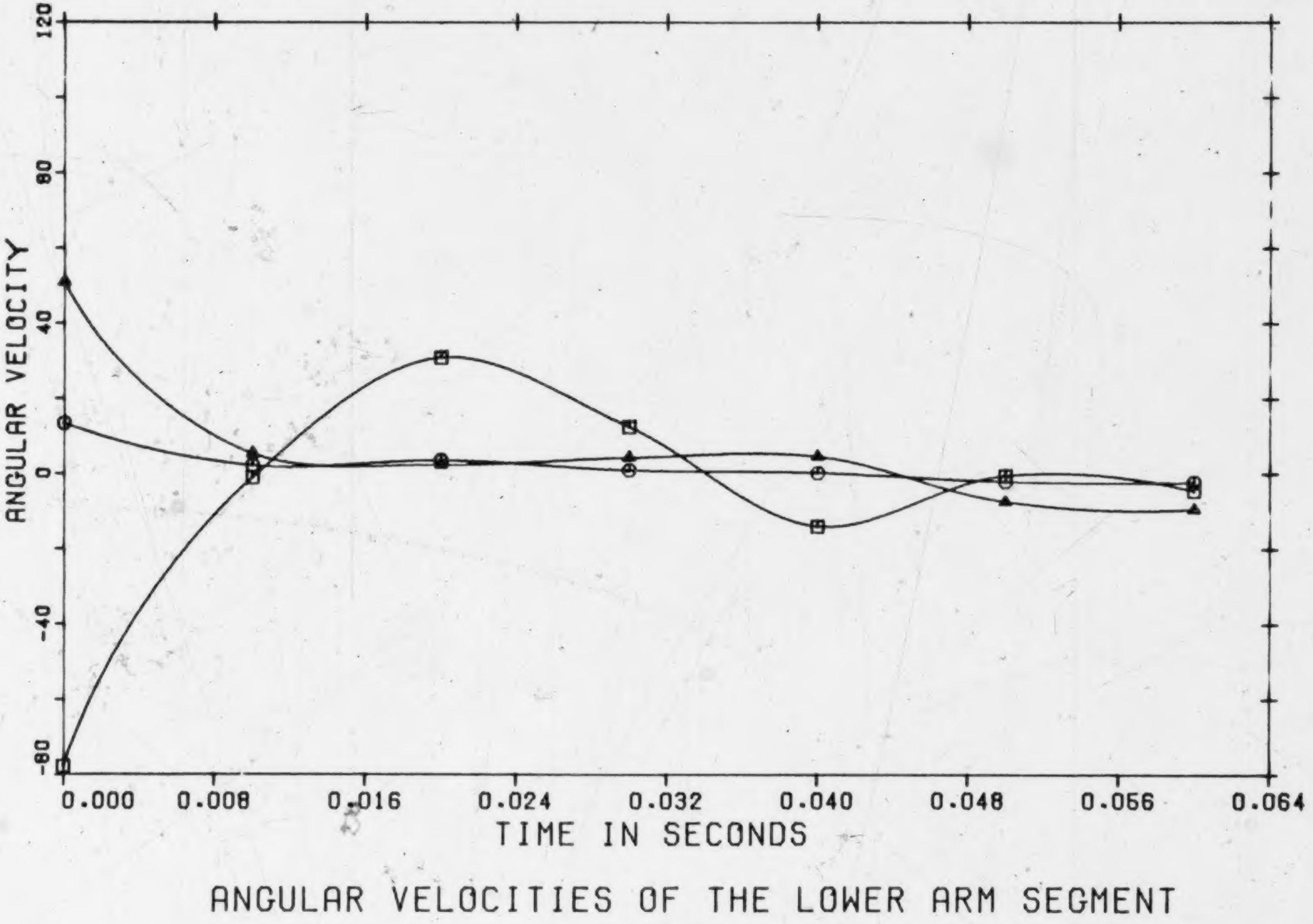


Figure 60. W1(□),W2(○), and W3(Δ) Angular Velocities for Subject 1.

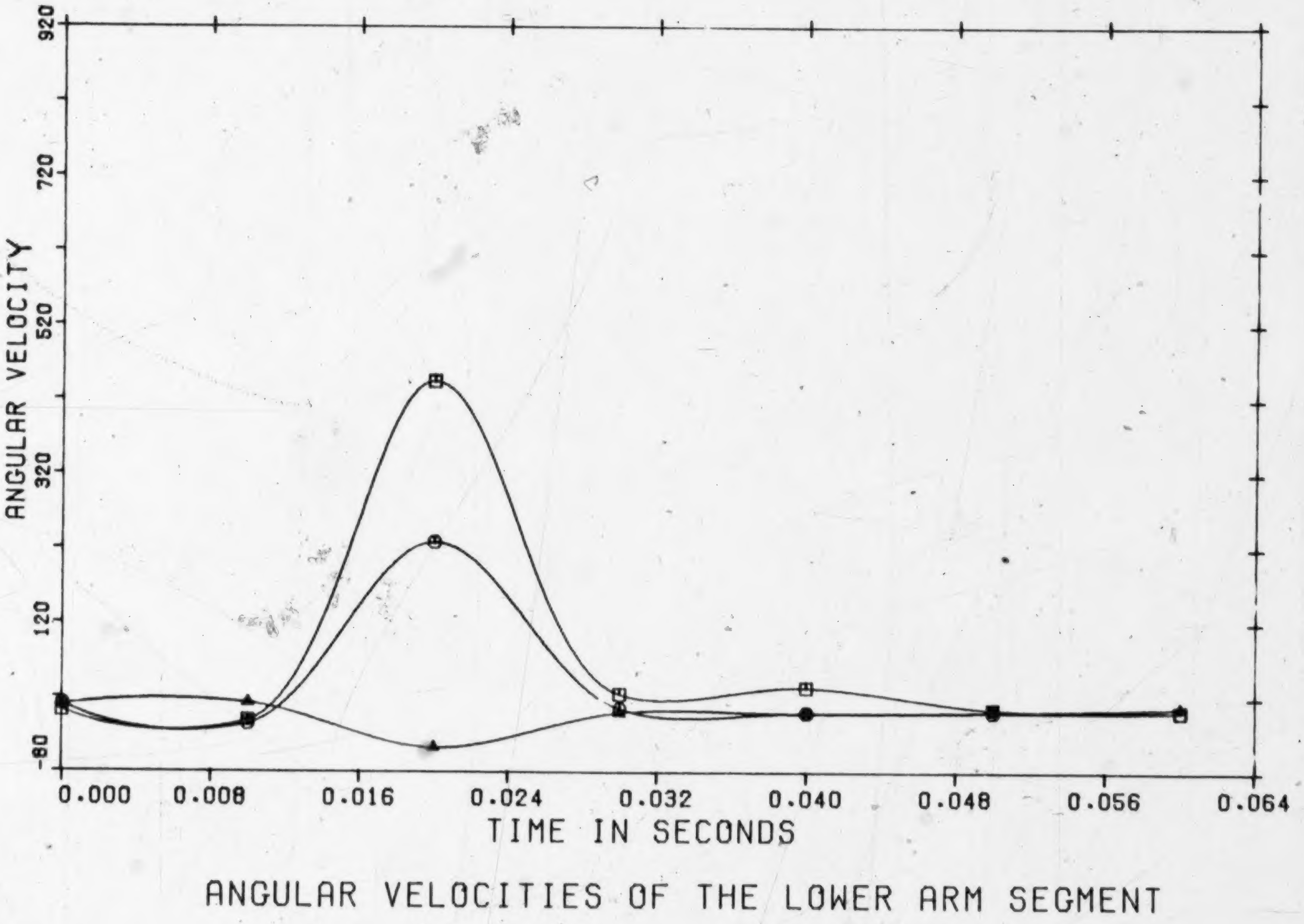


Figure 61. W1( ),W2( ), and W3( ) Angular Velocities for Subject 2.

each of the pitches analyzed are illustrated in Figures 60,61. It should be noted that these magnitudes may be open to question, due to the small number of points which were available to digitize in this analysis. Because the points necessary to digitize were obscured from the view of the rear camera, only eight frames were available to digitize for this skill. However, the cubic spline routine used to smooth this data has questionable values at the endpoints, so that it is recommended that three extra points are read in at the beginning and end of the frames of interest. In the present analysis, it was not possible to provide these extra points, so that the values reported for the first frames may be open to question.

Of the graphs of the two pitches analyzed, it is likely that the graph of the pitch of Subject 1, Figure 60, is open to question. This is likely due to a larger lag in the synchronization of the frames, or a less accurate estimate of the points digitized. However, this graph does illustrate a peak angular velocity in the w1 direction, which is that of the flexion movement at the elbow joint, which is likely accurate. However, this graph failed to illustrate the magnitude of the w2 rotation, which was the supination-pronation of this segment, probably due to these sources of error. The graph of the pitch of Subject 2, Figure 61, is likely a reasonable estimate of the magnitudes of these rotations. This graph illustrates a peak in the flexion angular velocity at the same instant as a peak in the pronation angular velocity, so that both of these joint movements are occurring at the same time to produce the resultant velocity of the ball. The magnitude of the abduction-adduction angular velocity is seen to be minimal, as is likely the case during this skill.

Although the reported angular velocities may provide fairly accurate estimates of the segment rotations, no attempt was made in the present study to verify these results. However, the development of this technique to estimate the amount of rotation occurring around all three axes of a given body segment should prove very useful to other researchers which are concerned with analysis of these movements in other, similar ballistic skills.

CHAPTER V

SUMMARY AND CONCLUSIONS

SUMMARY

This study was undertaken in an attempt to gain greater understanding of the factors which comprise a skilled performance in executing a ballistic movement. Although the specific movement chosen for the present analysis was the softball pitch, the general pattern of the segmental motions in this skill should be applicable to many similar skills. Four highly skilled subjects were filmed while performing the windmill pitch in softball. The filming was done using two cameras, a side view and a rear view. The film from the side view camera was analyzed in a single plane, and the relative motions of each of the segments of the pitching arm were calculated. The pitches were also performed while the subject pitched from a force plate, so that the recorded ground reaction forces could be compared to those calculated from film data. The film records of two of the pitches were synchronized and the digitized endpoints were read into a computer program which determined the spatial coordinates of each of the points of interest. The X,Y, and Z linear velocities of each of the segmental endpoints of the arm were calculated from these spatial coordinates. A method was also devised to calculate the angular velocities of each of the segments of the arm around their own principal axes.

These values were determined for the release frames of two of the pitches.

CONCLUSIONS

On the basis of the present study, the following conclusions seem justified:

1. Highly skilled softball pitchers are often larger than the average person, and this greater size may afford some advantage in performance of this skill.
2. The velocity of the pitched ball at release is considerably greater than the velocity of the pitching hand, and the magnitude of this difference may be related to the skill of the pitcher.
3. The force platform provides an accurate record of the ground reaction forces being exerted by the pitcher during delivery of the ball.
4. The peak vertical ground reaction forces occur just prior to release of the ball, while the horizontal force peak occurs much earlier in the skill.
5. There is a definite sequence of segment motions which characterize the highly skilled performer in this activity.
6. The larger, more proximal segment reaches maximum velocity at the earliest point in the skill, followed by the next segment, and finally the most distal segment. This sequence is seen in many other ballistic sports' skills, and is likely a necessary characteristic pattern of skilled performance.
7. The proximal segment also attains peak acceleration

earliest in the skill, followed by the peak accelerations of the distal two segments which occur at almost the same instant. This pattern is also likely characteristic of skilled performances.

8. The vector representing resultant of the X and Y component accelerations for each of the segments has a direction approximately 90 degrees to that of the resultant velocity vectors.

9. The magnitude of the joint forces at each of the joints is greatest just prior to release of the ball, at the point of maximum acceleration of the segments.

10. The vector representing the resultant direction of the joint forces also has a direction approximately 90 degrees to that of the resultant velocity vectors.

11. The joint moment of greatest magnitude in this skill was that occurring when the upper arm segment was slowing down prior to release of the ball.

12. It is likely that the most forceful muscle contraction in this skill is that occurring during the deceleration of the arm segment.

13. The computer program used in this study to produce three-dimensional coordinates from two-camera film data is a valid instrument to produce these points.

14. The Z-component of the velocity for each of the segmental endpoints of the arm is not especially important in this skill, as it maintains a rather constant, low value throughout the skill.

15. For ballistic skills of this type in which the vast majority of the motion is occurring in the X-Y plane, it is not necessary to use three-dimensional analysis.

16. When the coordinates of three non-colinear points are available for a given body segment, it is possible to estimate the magnitudes of the angular velocities occurring around the principal axes of these segments.

17. The peak value for the angular velocity of the supination movement of the lower arm segment occurs at the same instant as the peak value for the elbow flexion velocity.

18. The movement of the lower arm segment occurring around the longitudinal axis is of considerable importance in contributing to the final velocity of this segment.

The following findings are included as practical conclusions for the teacher or coach of softball pitching:

1. An extremely long step from the rubber is characteristic of all highly skilled pitchers, both to ensure a maximal push-off from the board, and to improve accuracy by flattening the arc of the hand.

2. An important coordination pattern to develop in the windmill pitch is the simultaneous motion of the stepping leg and the pitching arm at the beginning of this pitch.

3. This motion must be accompanied by a rotation of the whole body sideways toward the pitching arm, which places the body in a more advantageous position for the subsequent rotation towards the pitch.

4. The non-pivot foot must be placed in a position with the toe pointing directly towards the pitching plate, as any position with this toe pointing to the right causes a loss of medial rotation of the body around the left hip.

5. The pitching arm must be kept extended throughout the circular backswing motion, as the linear velocity is maximized at the end of a longer lever.

6. From the top of the backswing motion, the upper arm segment must be accelerated as forcefully and rapidly as possible. For this reason, the pitcher must have very strong shoulder flexors (pectoralis major, teres major, latissimus dorsi) and adductors.

7. The next important movement which occurs in the pitch in the rapid deceleration, or slowing down of the arm segment prior to release of the ball. This is an extremely critical movement, and the pitcher must have very strong shoulder extensors (posterior deltoid, rotator cuff muscles) to execute this effectively.

8. Another important force-producing movement in the pitch is the rotation of the arm segments medially. These movements include medial rotation of the arm segment at the shoulder joint, and pronation of the forearm segment just prior to release of the ball.

9. It is recommended that pitchers work on specific strengthening exercises for these rotation movements, rather than on the movements of wrist and elbow flexion which are of relatively minor importance in this skill.

10. The ability of the pitcher to impart maximum velocity to the ball at release (the effectiveness of the release of the ball), is likely dependent upon the strength of the athlete, and on the angular velocity of the pronation movement at release.

Recommendations

1. That a further study be attempted in which the films from each camera are exactly synchronized, so that the accuracy of the spatial coordinates may be improved.
2. That a further study be conducted to examine more closely the rotations occurring in each arm segment during the pitch.

BIBLIOGRAPHY

Alt,F. (ed.) Advances in Bioengineering and Instrumentation. New York: Plenum Press, 1966.

Andrews,James.G. "Biomechanical Analysis of Human Motion", in Kinesiology IV, American Association for Physical Education, Health and Recreation, 32-42, 1974.

Ariel, Gideon. "Computerized Biomechanical Analysis of Human Performance", in Mechanics and Sport, R.Bleustein,ed. New York: American Society of Mechanical Engineers, 1973.

Ariel, Gideon. "Method for Biomechanical Analysis of Human Performance", Research Quarterly, 45:72-79, 1974.

Ayoub,M.M. "Human Movement Recording for Biomechanical Analysis", International Journal of Production Research,10,p35-51, Jan. 1972.

Ayoub,M.M., Walvekar, A., and M. Petruno. "Biomechanical Model for the Upper Extremity Using Optimization Techniques", Report of the Society of Aeronautical Engineers, #N740272, 1974.

Bates, Barry T. "Indiana University Film Analysis Program-FILMDAT", unpublished computer program, Indiana University, 1974.

Baumann,W. "The Influence of Mechanical Factors on Speed in Tobagganing", Medicine and Sport, 8: Biomechanics III, 453-459, Baltimore: University Park Press, 1973.

Bergemann, Brian W. "Three-Dimensional Cinematography: a Flexible Approach," Research Quarterly, 45:302-308, 1974.

Black, Ruth Ann. "A Computer Program Designed to Analyze Three-Dimensional Motion", unpublished MSc. thesis, University of Saskatchewan, Saskatoon, 1977.

Broer, Marion R. Efficiency of Human Movement. Philadelphia: W.B. Saunders Co., 1973.

Bunn,J.W. Scientific Principles of Coaching,2nd edition. Englewood Cliffs, New Jersey: Prentice Hall, 1972.

Canadian Amateur Softball Association. 1978 Official Softball Rules, Ottawa: Canadian Amateur Softball Association, 1978.

Carlin,Eleanor J. "Mechanics of the Shoulder Girdle", American Journal of Occupational Therapy,17, 49, 1963.

Cavanagh, Peter and Robert J. Gregor. "Knee Joint Torque During the Swing Phase of Normal Treadmill Walking", Journal of Biomechanics, 8, 337-344, 1974.

Cavanagh, Peter R. and Jean Landa. "A Biomechanical Analysis of the Karate Chop", Research Quarterly, 47:610-618, 1976.

Chaffin, Don B. "A Computerized biomechanical Model--development of and use in studying gross body actions," Journal of Biomechanics, 2, 429-441, 1969.

Chao, Edmund and Kim, Kuan. "Application of Optimization Principles in Determining the Applied Moments in Human Leg Joints During Gait", Journal of Biomechanics, 6, 497-510, 1973.

Chao, Edmund and B. F. Morrey. "Three dimensional Kinematic Analysis of the Human Elbow-a Linkage with the Trochoginglymoid Joint", Oklahoma State Applied Mechanics Conference, Nov 3-5, 1975.

Chao, Edmund and B. F. Morrey. "Three dimensional Rotation of the Elbow", Journal of Biomechanics, 11:57-73, 1978.

Contini, R. and R. Drillis. "Biomechanics", Applied Mechanics Review, 7, 49-52, 1954.

Cooper, J. M. (ed.) Selected Topics on Biomechanics. Chicago: The Athletic Institute, 1971.

Cooper, J. M. and R. Glassow. Kinesiology, 3rd ed. St. Louis: C.V. Mosby Co., 1972.

Cureton, Thomas K. "Elementary Principles and Techniques of Cinematographic Analysis as Aids to Athletic Research", Research Quarterly, 10:3-23, 1939.

Dapena, Jesus. 'Three Dimensional Cinematography with Horizontally Panning Cameras", unpublished research paper, University of Iowa Biomechanics Laboratory, 1976.

Dempster, Wilfred T. "Mechanisms of Shoulder Movement", Archives of Physical Medicine and Rehabilitation, 46, 49-, 1965.

Dempster, W.T., L.A. Scherr and J.G. Preist. "Conversion Scales for Estimating Humeral and Femoral Lengths and the Lengths of Functional Segments", Human Biology, 36, 1964.

Dern, R.J., Levene, J.M., and H.A. Blair. "Forces Exerted at Different Velocities in Human Arm Movement", American Journal of Physiology, 151, 415-437, 1947.

Diffrient, Niels, A.R. Tilley and J.C.Bardigjy. "Humanscale1/2/3", Cambridge: Massachussets Institute of Technology Press, 1974.

Dillman,Charles J. Muscular Torque Patterns of the Leg During the Recovery Phase of Sprint Running. unpublished PhD. dissertation, Pennsylvania State University, 1970.

Dillman, Charles J. "A Kinetic Analysis of the Recovery Leg During Sprint Running", in Biomechanics, J.M.Cooper, ed., 137-165, Chicago: The Athletic Institute, 1971.

Dobson,M. and B. Sisley. Softball for Girls. New York: Ronald Press Co., 1971.

Doolittle,T.L. "Errors in Linear Measurement With Cinematographical Analysis", Kinesiology Review, 1971, 32-38, American Association of Health, Physical Education and Recreation, 1971.

Duvall, Ellen N. "Critical Analysis of Divergent Views of Movement at the Shoulder joint," Archives of Physical Medicine and Rehabilitation,36,149, 1955.

Duquet,W., Bormes,J. and Hebbelinck,M. 'A Method of Three-Dimensional Analysis of Twisting Movements', Medicine and Sport, Biomechanics III,8, 175-180,1973.

Eberhart,H.D. and V.T.Inman. "An Evaluation of Experimental Procedures Used in a Fundamantal Study of Human Locomotion", in Annals of the New York Academy of Science, 51, 1213-1228, 1951.

Engen,T.J. and W.A.Spencer. "Method of Kinematic Study of Normal Upper Extremity Movements", Archives of Physical and Medical Rehabilitation, 49, 9-12, 1968.

Fenn, W.O., H. Brody and A. Petrelli. "The Tension Developed by Human Muscles at Different Velocities of Shortening", American Journal of Physiology, 97, 1-14, 1931.

Gierke,H.E. "Dynamic Characteristics of the Human Body", in Biomedical Engineering, R.Kenedi,ed. Baltimore: University Park Press, 1972.

Gowitzke,B.A. and D.B.Waddell. "The Contributions of Biomechanics in Solving Problems in Badminton Stroke Production", paper presented at the International Badminton Coaching Conference, Malmo, 1977.

Groves, Gordon W. "Acceleration Referred to Moving Curvilinear Coordinates", American Journal of Physics,10,927-29, 1967.

Gutewort,W. "The Numerical Presentation of the Kinematics of Human Body Motions, Medicine and Sport, Biomechanics II, 6, 290-298, 1971. p 33 38

Hanavan,E.P. A Mathematical Model of the Human Body. Wright-Patterson Air Force Base, Ohio, 1964.

Harrs, Norma. "Requium for a Wrist Snap", Racquets Canada, 81-84, March, 1978.

Hay,James G. The Biomechanics of Sports Techniques. Englewood Cliffs, New Jersey: Prentice Hall, 1973.

Hay,James G., James G. Andrews, Jesus Dapena and Barry D. Wilson. "The Limiting Factors Approach to the Analysis of Human Movement", unpublished research paper, University of Iowa, 1976a.

Hay, James G., Barry D. Wilson, and Jesus Dapena. "A Research Strategy for Identifying Limiting Factors in the Performance of a Motor Skill", in Biomechanics V-B, Baltimore: University Park Press, 1976b.

Hay, James G., Barry D. Wilson and Jesus Dapena. "A Computational Technique to Determine the Angular Momentum of the Human Body", Journal of Biomechanics, 10, 269-277, 1977.

Hay, James G., Jesus Dapena, B.D. Wilson, J.G. Andrews and G. Woodworth. "An analysis of joint contributions to the Performance of a Gross Motor Skill", paper presented to the VI Annual conference on Biomechanics, Copenhagen, 1977.

Hegarty, John C. "Student Experiment on Coriolis Force", American Journal of Physics, 34, 157-159, 1966.

Hubbard, Alfred W. "Photography", in Biomechanics of Sport, Thomas P. Martin, ed. State University of Bridgeport, 1975.

Huston,R.L. and C.E.Passerello. "On the Dynamics of a Human Body Model", Journal of Biomechanics, 4, 369-378, 1971.

Jacobsen, Stephen C. and Robert W. Mann. "The Analytical Derivation of a Controller for a Multi-axis Artificial Arm," in 26th ACEMB Meeting, 1973.

Jensen, Robert K. A System of Standardized Biomechanical Force Measurements. PhD. dissertation, University of Alberta, 1972.

Kane,T.R. "Self Rotation of Animate Beings", Medicine and Sport, Biomechanics II, 6, 212-218, 1971.

Kane,T.R., M.R. Headrick and J.D. Yatteau. "Experimental

Investigation of an Astronaut Maneuvering Scheme", Journal of Biomechanics, 5, 313-320, 1972.

Kane, T.R. and M.P.Scher. "Human Self-Rotation by Means of Limb Movements", Journal of Biomechanics, 3, 39-49, 1970.

Karas,V. and A.Stapleton. "Application of the Theory of the Motion System in the analysis of Gymnastic motions", Medicine and Sport, Biomechanics I, 2, 192-195, 1967.

Kenedi, R.M. Biomechanics and Related Bioengineering Topics. New York: Pergamon Press, 1965.

Kinzel,G.L., A.S. Hall and B.M.Hillberry. "Measurement of the Total Motion Between Two Body Segments--I Analytical Development," Journal of Biomechanics, 5, 93-105, 1972.

Kinzel,Gary and B.M.Hillberry. "A Method for Measuring the Total Motion Between Two Body Segments", in Biomechanics, J.M.Cooper, ed., 223-232, Chicago: The Athletic Institute, 1971.

Kirby, R.F. "Mechanics of the Windmill Pitch", Athletic Journal, 49(7):62, March, 1969.

Kneer, Marian and Charles McCord. Softball-Slow and Fast Pitch. Dubuque, Iowa: W.C. Brown Co. Ltd. 1976.

Koniar,M. "The Biomechanical Studies on the Superposition of Angular Speeds in Joints in Lower Extremities of Sportsmen", Medicine and Sport, Biomechanics III, 8, 426-428, 1973.

Kroemer,K.H.E. "Human Strength: Terminology, Measurement, and Interpretation of Data," Human Factors, 12, 297-313, 1970.

Lamb,H. and P. Stothart. "A Comparison of Cinematographic and Force Platform Techniques for Determining Takeoff Velocity in the Vertical Jump," paper presented to the VI Annual conference of Biomechanics, Copenhagen, 1977.

Le Veau,Barney. Williams and Lissner: Biomechanics of Human Motion. Philadelphia: W.B. Saunders Co., 1977.

Leviton, Dan. "The Windmill Pitch", in T. Martin, ed., Biomechanics of Sport, Brockport, New York: State University Print Shop, 1975.

Lindner,E. "The Phenomenon of Lateral Deviation in Throwing", Medicine and Sport, Biomechanics II, 6, 123-127, 1971.

Liu,Y.K. and J.K.Wickstrom. "Estimation of the Inertial

Property Distribution of the Human Torso from Segmented Cadaveric Data," in Kenedi,R.,ed. Perspectives in Biomedical Engineering, Baltimore: University Park Press,1972.

Macmillan,M.B. "The Determinants of the Flight of the Kicked Football", Research Quarterly, 46, 48-57, 1975.

Macmillan,M.B. "The Kinesiological Determinants of the Path of the Foot During the Football Kick", Research Quarterly, 47, 33-40, 1976.

Martin, Thomas P. Biomechanics of Sport. Brockport, New York: State University Print Shop, 1975.

Martin,T.P. and Martin B. Pongratz. "Validation of a Mathematical Model for Correction of Photographic Perspective Error", Biomechanics IV. Baltimore: University Park Press, 1974.

McDonald,James E. "The Coriolis Effect", Scientific American, 73, May, 1972.

McLaughlin, Thomas M., Charles Dillman and T.J. Lardner. "Biomechanical Analysis with Cubic Spline Functions" Research Quarterly, 48:569-582, 1977.

Meriam, J.L. Dynamics-SI Version. New York: John Wiley and Sons, Inc., 1975.
Miller, Doris I. "A Computer Simulation of the Airbourne Phase of Diving", in Biomechanics, J.M.Cooper, ed., 207-215, Chicago: The Athletic Institute, 1971.

Miller, Doris I. and D.J.East. "Kinematic and Kinetic Correlates of vertical Jumping in Women", Biomechanics V-B, 65-72, Baltimore: University Park Press, 1976.

Miller, Doris I. and R.C.Nelson. Biomechanics of Sport. New York: Lea and Febiger, 1973.

Miller, Doris I. A Computer Simulation Model of the Airborne Phase of Springboard Diving. unpublished PhD. dissertation, Pennsylvania State University, 1970.

MIller, Doris I. and K.L. Petak. "Three-Dimensional Cinematography", in Thomas Martin, ed., Biomechanics of Sport, State University of Bridgeport, 1975.

Miller, Doris I. and William E. Morrison. "Prediction of Segmental Parameters using the Hanavan Human Body Model", Medicine and Science in Sports, 7, 207-212, 1975.

Miller, Robert G. and C.T. Shay. "Relationship of Reaction Time to the Speed of a Softball", Research Quarterly, 35:433-437, 1964.

Moore, Kenny. "Gideon Ariel and His Magic Machine", Sports Illustrated, August 22, 1977, 53.60.

Nelson, R.C. "Biomechanics of Sport", in Biomechanics III, Baltimore: University Park Press, 1973.

Nelson, R.C. and Doris I.Miller. "Cinematography in Biomechanics Research", in Thomas Martin, ed., Biomechanics of Sport, State University of Bridgeport, 1975.

Noble, Marion L. and David L. Kelley. "Accuracy of Triaxial Cinematographic Analysis in Determining Parameters of Curvilinear Motion", Research Quarterly, 40:643-644, 1969.

Noss,J. "Control of Photographic Perspective in Motion Analysis", JOHPER, 7, 81-84, September, 1967.

Nubar,Y. and R. Contini. "A Minimal Principle in Biomechanics", Bulletin of Mathematical Biophysics, 23, 337-391, 1961.

Oberg, K. "Mathematical Modelling of the Human Gait: an Application of the SELSPOT system", Biomechanics IV, 79-84, Baltimore: University Park Press, 1974.

O'Malley,Martin. "Reflections of an aging first baseman upon that most excellent game, softball", Maclean's, p.65, September 19, 1977.

Otahal,S. "Mechanical Model of Some Functions of the Motion System of Man, and Its' Analysis Based on Matrix Algebra", Medicine and Sport, 2, 188-191, 1967.

Padgaonkar,A., K. Kreiger, and A. King. "Measurement of Angular Acceleration of a Rigid Body Using Linear Accelerometers", Journal of Applied Mechanics, 42, 552,556, 1975.

Panjabi,M. "A Mathematical Approach for the Three-Dimensional Analysis of the Mechanics of the Spine", Journal of Biomechanics, 4, 203-211, 1971.

Payne,A.H. "The Use of Force Platforms for the Study of Physical Activity." in J.Wartenweiler,ed., Biomechanics I, 83-86, Baltimore: University Park Press, 1968a.

Payne,A.H.,W.J.Slater, and T. Telford. "The Use of Force Platform in the Study of Athletic Activities", Ergonomics, 11:123-143,1968b.

Payne,A.H. "A Force Platform System for Biomechanics

Research in Sport", in R.Nelson, ed., Biomechanics IV, Baltimore: University Park Press, 1974.

Pearlman,N. "Vector Representation of Rigid-Body Rotation", American Journal of Physics, 35, 1164, 1967.

Pearson,J.R., D.R. McGinley, and L.M. Butzel. "A Dynamic Analysis of Upper Extremity Planar Motions", Human Factors, 5, 59-70, 1963.

Penrose,T., G. Wood and B. Blanksby. "The Accuracy of Positional Data in Triaxial Cinematography", Australian Journal of Physical Education, 71:7-12, 1976.

Pezzack,J.C., R. Norman, and D.A.Winter. "An Asessment of Derivative Determining Techniques Used for Motion Analysis", Proceedings of 11th International Conference on Medicine and Biological Engineering, Ottawa: Conference Committee 1977.

Plagenhoef, Stanley. "Methods for Obtaining Kinetic Data to Analyze Human Motions", Research Quarterly, 37:103-112,1966.

Plagenhoef,Stanley. "A Kinetic Analysis of Running", Track and Field Quarterly Review, October, 56-63, 1968.

Plagenhoef, Stanley. "Computer Programs for Obtaining Kinetic Data on Human Movement", Journal of Biomechanics, I, 221-234, 1968.

Plagenhoef, Stanley. Patterns of Humn motion. Englewood Cliffs, New Jersey: Prentice-Hall, 1971.

Plagenhoef, Stanley. "The Joint force and Moment Analysis of all Body Segments when Performing a Non-Symmetrical Three-Dimensional Motion", Medicine and Sport, Biomechanics III, 8, 165-171, 1973.

Provins,K.A. "Effect of Limb Position on the Forces Exerted About the Elbow and Shoulder Joints on the Two Sides Simultaneously", Journal of Applied Physiology, 7, 387-389, 1955.

Quigley,Brian M. and D.B.Chaffin. "A Computerized Biomechanical Model Applied to Analysis of Skiing", Medicine and Science in Sports, 3, 89-96, 1971.

Ramey, M.R. "Use of force Plates for Long Jump Studies", in Biomechanics III, Baltimore: University Park Press, 1973.

Ramey,M. and Clarence Nicodemeus. "A Note on the Determination of Angular Velocities in Human Motion Studies", Medicine and Science in Sports, 9, 134-136, 1977.

Ramsey,J.R. "The Quantification of Human Effort and Motion for the Upper Limbs", International Journal of Production Research, 7, 47-59, 1968.

Rasche,P.J. and R.K.Burke. Kinesiology and Applied Anatomy. Philadelphia: Lea and Febiger, 1974.

Reed,W.S. and R.E.Garrett. "A Three-Dimensional Human Form and Motion Simulation", Kinesiology Review, 1971, American Association of Health, Physical Education and Recreation, 60-65, 1971. p 100 110

Roberts,Elizabeth M. "Cinematography in Biomechanical Investigation", in Biomechanics of Sport, Thomas Martin, ed., State University of Bridgeport, 1975.

Roberts, Elizabeth M. and A. Metcalfe. "Mechanical Analysis of Kicking", in Medicine and Sport, Biomechanics I, 2, 315-319, 1968.

Roberts, Elizabeth M., R.F.Zernicke, Y.Youm and T.C.Huang. "Kinetic Parameters of Kicking", Biomechanics IV, 157-162, Baltimore: University Park Press, 1974.

Salter, N. and H.D.Darcus. "The Amplitude of Forearm and of Humeral Rotation", Journal of Anatomy, 87, 407, 1953.

Seabloom, Robert W. Vector Algebra for Engineers. New York: McGraw-Hill Book Co., 1965.

Slocum,D.B. and S.L.James. "Biomechanics of Running", Journal of American Medical Association, 721-728, 1968.

Smith, A.J. "Photographic Analysis of Movement", in Techniques for the Analysis of Human Movement, London: Lepus books, 1975.

Steindler,Arthur. Kinesiology of the Human Body Under Normal and Pathological Conditions. New York: Charles C. Thomas Co., 1955.

Sukop, Jiri, K.L.Petak, and R.C. Nelson. "An On-Line Computer System for Recording Biomechanical Data", Research Quarterly, 42:101-102, 1971.

Susanka, P. "Computer Techniques in the Biomechanics of Sport", Biomechanics IV, Baltimore: University Park Press, 531-534, 1974.

Sutherland, D.H. and J.L.Hagy. "Measurement of Gait Movements from Motion Picture Film", Journal of Bone and Joint Surgery, 54-A, 787-797, 1972.

Taylor,C.L. and A.C. Blashke. "A Method for Kinematic Analysis of the Motions of the Shoulder, Arm, and Hand Complex", Annals of the New York Academy of Science, 51, 1251, 1951.

Thurnaur, Peter G. "Kinematics of Finite, Rigid-Body Displacements", American Journal of Physics, 35, 1145-1154, 1967.

Van Gheluwe, B. "A New Three-Dimensional Filming Technique Involving Simplified Alignment and Measurement Procedures", in R. Nelson, ed., Biomechanics IV, Baltimore: University Park Press, 1974.

Van Gheluwe, B. "Errors Caused by Misalignment of the Cameras in Cinematographical Analysis", Research Quarterly, 42:153-161, 1975.

Van Gheluwe, B. "Computerized Effortless Three-Dimensional Cinematography for any Arbitrary Camera Set-Up". Paper presented to the VI Annual Congress of Biomechanics, Copenhagen, 1977.

Waddell,D.B. and B.A.Gowitzke. "Analysis of Overhead Badminton Power Strokes Using High Speed Bi-Plane Photography", paper presented at International Badminton Coaching Conference, Malmo, 1977.

Wainwright,S.A., W.D.Briggs, J.D.Currey, and J.M.Gosline. Mechanical Design in Organisms. New York: John Wiley and Sons, 1976.

Wells,K and K. Luttgens. Kinesiology, 6th edition. New York: W.B. Saunders Co., 1976.

Widule, Carol J. and D.C. Gossard. "Data Modelling Techniques in Cinematographic Research", Research Quarterly, 42:103-111, 1971.

Widule, Carol J. Segmental Moment of Inertia Scaling Procedures", Research Quarterly, 47:143-147, 1976.

Youm,Y. and Y. Yoon. "A Mechanical Model for Upper Extremity Motion Analysis." unpublished research paper, University of Iowa, 1977.

Youm,Y., A.E.Flatt, and B.S.Sprague. "Forearm Rotation", in M.Cannon, ed., Proceedings of the 5th New England Bioengineering Conference, 78-86, New York: Pergamon Press, 1977.

Youm,Y., T.C.Huang, R.F.Zernicke and E.M.Roberts. "Mechanics of simulated Kicking", in Mechanics and Sport, New York:

ASME, 1973.

Zernicke, Ronald F., J. Garhammer and F.W.Jobe. "Human Patellar Tendon Rupture", Journal of Bone and Joint Surgery, 59-A, 179-183, 1977.

Zernicke, R.F. and E.M.Roberts. "Human Lower Extremity Kinetic Relationships during Systematic Variations in Resultant Limb Velocity", Biomechanics V-B, 20-25, Baltimore: University Park Press, 1976.

Zollinger,R.L. "Mechanical Analysis of the Windmill Fast Pitch in Women's Softball", Research Quarterly, 44,290-300, October, 1973.

APPENDIX A

Filming Data

Filming Data

Date: February 25, 1978.

Location: Dance Gymnasium, University of Alberta

Camera Placement:
Camera 1: 50 feet 9 inches from center of force platform
Camera 2: 40 feet 0 inches to the rear of the force platform

Camera Settings:
Frame Rate: 100 fps
Shutter Angle: 30 degrees
Exposure Time: .0008333 sec
f/stop: 4.0
Light Reading: 12 din
Artificial Lights: 6-1200 watt television lights and overhead dance lights
Background: Black curtain
Film: Kodak Ectachrome 7240 ASA 125

APPENDIX B

Three Dimensional Program Description

3-D PROGRAM DESCRIPTION

INTRODUCTION

Continuous improvement of instrumentation and technical procedures is a general and basic characteristic in all experimental sciences. A review of the last decade proves this to be true for cinematographical movement analysis in biomechanical research: from planar or two-dimensional filming to the first threedimensional recording systems with cameras aligned along the axes of an orthogonal Cartesian reference frame (Noble & Kelly, 1969; Duquet, Borms and Hebbelinck, 1973; Miller, 1973) and further to more sophisticated techniques with camera set-ups free from positional restrictions except for optical axes intersection (Bergeman, 1974; Van Gheluwe, 1974).

In a recent study (Penrose, Wood and Blanksby, 1976) it is even no longer necessary for the optical axes to intersect one another, although a theodolite is required in order to get precise spatial information of cameras and reference points.

This paper presents a further refinement in the area of threedimensional cinematography. The camera set-up is completely free of any geometrical or spatial restriction (optical axes intersection is not required). The use of a theodolite or other alignment or measuring tool is absolutely unnecessary as the external parameters (defining the spatial position and orientation of the cameras) are automatically calculated by the computer. Knowledge of intrinsic parameters, such as focal length, film format etc... is not required either.

All these features make threedimensional filming so flexible that it can be used in game- or competitive-like situations with relative ease of operation and without tedious and time consuming preparations.

METHOD

The basic principle of this system relies on the implicit mathematical reconstruction of the position of the cameras in space using the known life size coordinates and the image coordinates of certain reference points. These are located on a steel three-axial reference frame (fig. 1) which coincides with the mathematical coordinate system defining the objects space (= space where the real movement is described analytically by its X, Y and Z coordinates).

With the foregoing information about position and orientation of the cameras it is possible to calculate the X, Y and Z coordinates of any arbitrary point in space, provided its image coordinates are known.

Theoretical basis of the method.

The mathematical theory underlying the method is basically the same as described by the author in a preceding publication (Van Gheluwe, 1974). Defining an orthogonal coordinate system (O, X, Y, Z) in space, the motion of any arbitrary point can be described analytically by its spatial coordinates X, Y and Z (fig. 2) (a).

Using matrix calculus and analytical geometry, it is possible to derive a set of four linear equations expressing a relationship between the life size X, Y and Z coordinates of an arbitrary point in space and its known image coordinates (x_1 , y_1) and (x_2 , y_2) :

$$\begin{aligned}
(n_{11} - x_1 n_{31}) X + (n_{12} - x_1 n_{32}) Y + (n_{13} - x_1 n_{33}) Z + x_1 &= 0 \\
(n_{21} - y_1 n_{31}) X + (n_{22} - y_1 n_{32}) Y + (n_{23} - y_1 n_{33}) Z + y_1 &= 0 \\
(m_{11} - y_2 m_{31}) X + (m_{12} - x_2 m_{32}) Y + (m_{13} - x_2 m_{33}) Z + x_2 &= 0 \\
(m_{21} - y_2 m_{31}) X + (m_{22} - y_2 m_{32}) Y + (m_{23} - y_2 m_{33}) Z + y_2 &= 0
\end{aligned} \tag{1}$$

where n_{ij} and m_{ij} $(i = 1, 2, 3;\ j = 1, 2, 3)$ are matrix coefficients relating to the position and orientation of the cameras.

These coefficients are calculated at an earlier stage of the computing process using the same equations as above, with the help of the known spatial X, Y and Z coordinates of certain reference points.

Taking 21 of these points (7 on each axis of the steel reference frame), one can derive 6 sets of 14 linear equations. Solving them yields respectively n_{11}, n_{21}, n_{31} for the first set, n_{12}, n_{22}, n_{32} for the second, etc... till m_{13}, m_{23}, m_{33} for the last one.

Substituting them in the set of equations 1 above, makes it possible to solve these equations for the life size X, Y and Z coordinates of any arbitrary point in space.

All the mentioned sets of equations are overdefined (having more equations than unknown variables), especially the sets defining the matrix coefficients n_{ij} and m_{ij}, in order to assure the accuracy and the stability of the results.

The solving technique for all these sets of equations relies on the application of iterative "least square fitting" methods.

Reliability of the method.

Several experiments proved the accuracy of the final X, Y and Z coordinates to depend strongly on the measuring precision of the operator collecting the image coordinates and on the resolution of the used x-y-reader. On the contrary, calculation errors, inherent in solving the set of equations using the "least square fitting", and the rounding errors during computation, were negligible.

The results of one particular test reconstructing 17 linear distances between knots of a grid located on a transparent cylinder, are shown in table $1^{(b)}$.

The largest deviation found in this test did not exceed .2 cm and the mean deviation fluctuated around .1 cm.

APPLICATIONS

The method described above can be used in all circumstances and for any purpose where threedimensional reconstruction is required.

It requires but three simple preparative actions before real filming can start:

1. set the cameras so as to obtain the correct pictures
2. put the steel reference frame somewhere in the field of vision of the

cameras

3. film this reference frame with both cameras and remove it afterwards if necessary.

Therefore this method is especially appropriate to field-work in game- or competition-like situations, where minimal interference from "outside people" is allowed and where speed and ease of operation are decisive factors whether threedimensional filming will be possible or not.

The method as described above was applied successfully in a study analysing different styles of long jumping and was also used in an indoor swimming pool for a comparative study of four different starts in swimming.

In another, medically oriented study, the spatial position of 120 electrodes all around a human torso had to be reconstructed. Not fewer than six cameras were positioned around the body in order to have each electrode recorded by at least two cameras.

CONCLUSION

The threedimensional filming technique as presented above combines an unprecedent ease of operation with high reliability and accuracy of results. Therefore it is especially recommended for field-work in threedimensional movement recording.

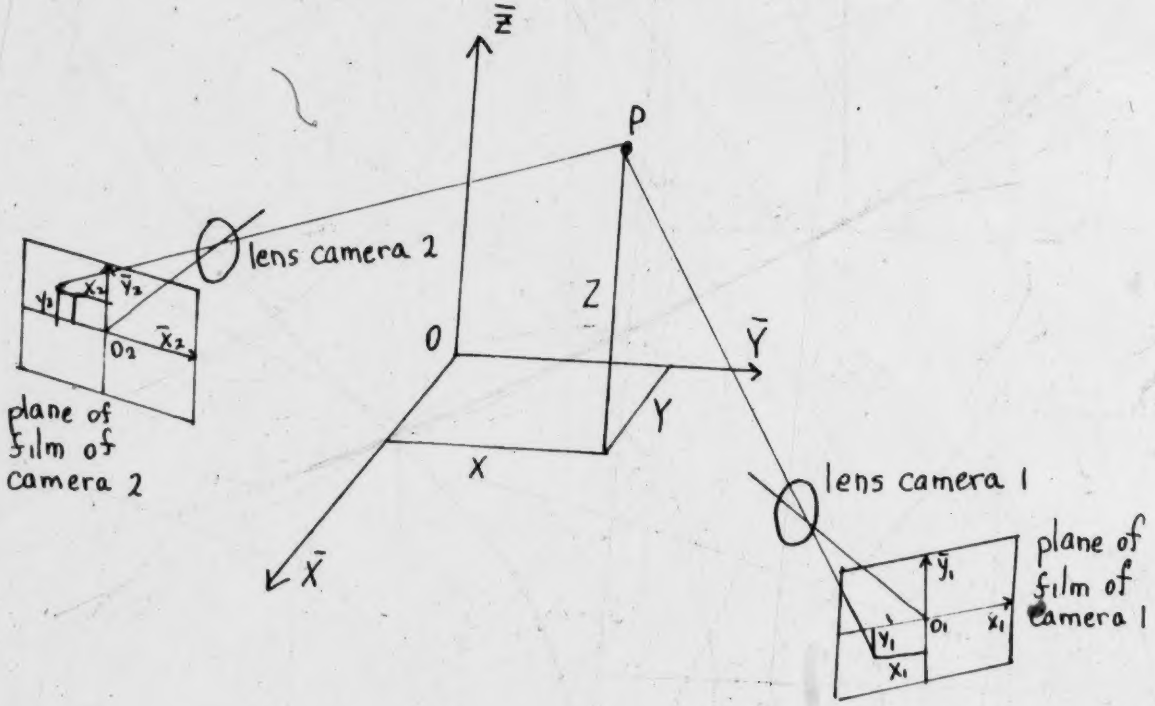

$\bar{Z}$
P
lens camera 2
Z
0
$\bar{Y}$
Y
X
$\bar{X}$
x_2
$\bar{y}_2$
y_2
O_2
$\bar{x}_2$
plane of film of camera 2
lens camera 1
$\bar{y}_1$
y_1
O_1
$\bar{x}_1$
x_1
plane of film of camera 1

Figure 62. Position of Cameras in Space.

APPENDIX C

Equations for Planar Analysis

KEY TO SYMBOLS

A - shoulder joint

B - elbow joint

C - wrist joint

D - fingertips

G_1 - center of gravity of the upper arm segment

G_2 - center of gravity of the lower arm segment

G_3 - center of gravity of the hand segment

$\overline{r_1}$ - position vector of the upper arm segment

$\overline{r_2}$ - position vector of the lower arm segment

$\overline{r_3}$ - position vector of the hand segment

1, 2, 3 - subscripts representing the upper, lower and hand segments of the upper extremity, respectively

θ_1 - the angle of segment 1 with the right horizontal

θ_2 - the angle of segment 2 with the right horizontal

θ_3 - the angle of segment 3 with the right horizontal

x, y - subscripts representing vectors in the x and y directions

S_{Ax}, S_{Ay}, S_{Bx}, S_{By}, S_{Cx}, S_{Cy}, S_{Dx}, S_{Dy} - the displacement vectors of the four segmental endpoints

V_{Ax}, V_{Ay}, V_{Bx}, V_{By}, V_{Cx}, V_{Cy}, V_{Dx}, V_{Dy} - the velocity vectors of the four segmental endpoints

A_{Ax}, A_{Ay}, A_{Bx}, A_{By}, A_{Cx}, A_{Cy}, A_{Dx}, A_{Dy} - the acceleration vectors of the four segmental endpoints

$\overline{W_1}$, $\overline{W_2}$, $\overline{W_3}$ - angular velocities of the three segments

$\overline{\alpha}1$, $\overline{\alpha}2$, $\overline{\alpha}3$ - angular accelerations of the three segments

M_1, M_2, M_3 - masses of the three segments

I_1, I_2, I_3 - moments of inertia of each of the three segments around an axis through the center of gravity

W_1, W_2, W_3 - weights of each of the three segments

CALCULATION OF GROUND REACTION FORCES

In the calculation of the ground reaction forces, the system is defined as the body of the subject. Rotation of the body may be neglected in the measurement of forces in this skill (Miller and Nelson, 1973: 54). The system may be represented as a particle (the mass center) with mass equal to that of the subject.

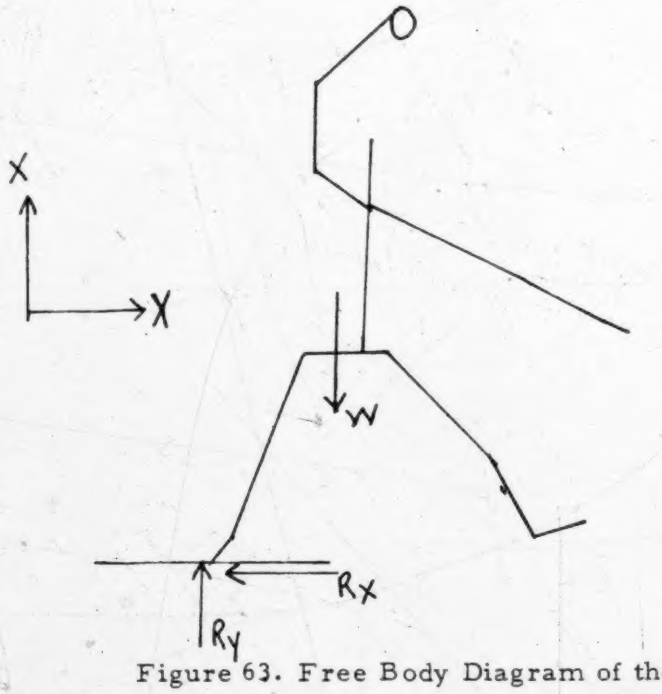


Figure 63. Free Body Diagram of the Softball Pitch

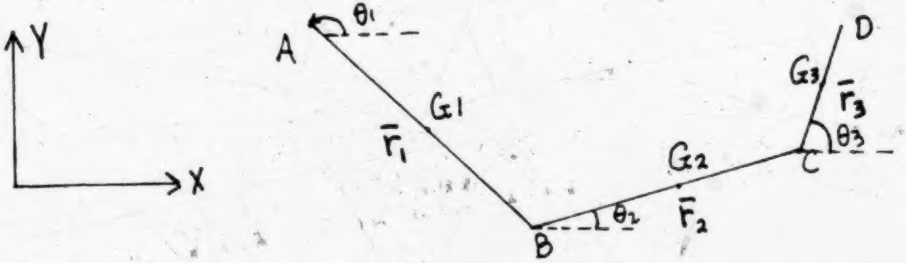
The free body diagram indicates that the body weight acts vertically downward from the mass center. The magnitudes of the forces at successive points during the takeoff were determined by application of Newton's second law of motion. The equations of motion may be expressed as: (Miller & Nelson, 1973: 55)

$$\Sigma F_x = M_{ax} \qquad \Sigma F_y = M_{ay}$$

$$R_x = M_{ax} \qquad R_y = M_{ay} + W$$

The application of these equations to the forces exerted by the pitcher at successive points during the pitch was accomplished by a computer program written by the author. The R_x and R_y reaction forces were then displayed against time to illustrate the magnitudes and directions of such forces. These calculated body reaction forces were then compared to the tracings from a force plate from which the subject pitched the ball.

KINEMATICS OF THE UPPER EXTREMITY MODEL



1. Let S_A be the absolute linear displacement of point A, which represents the shoulder joint. Then S_A may be divided into two components, in the X and Y directions; and each of these positions may be plotted against time to produce a displacement-time curve. This curve may then be differentiated once to produce velocity in the X (or Y) direction; and twice to produce acceleration in the X (or Y) direction.

2. To find $\overline{V}_B$ (elbow joint): $\overline{V}_B = \overline{V}_A + \overline{W}_1 \text{ X } \overline{r}_1$

   or $\overline{V}_{Bx} = \overline{V}_{Ax} + (\overline{W}_1 \text{ X } \overline{r}_1)\,x$

   $\overline{V}_{By} = \overline{V}_{Ay} + (\overline{W}_1 \text{ X } \overline{r}_1)\,y$

3. To find $\overline{A}_B$ (elbow joint): $\overline{A}_B = \overline{A}_A + \overline{\alpha}_1 \text{ X } \overline{r}_1 + \overline{W}_1 \text{ X} (\overline{W}_1 \text{ X } \overline{r}_1)$

   or $\overline{A}_{Bx} = \overline{A}_{Ax} + (\overline{\alpha}_1 \text{ X } \overline{r}_1)_x + \overline{W}_1 \text{ X } (\overline{W}_1 \text{ X } \overline{r}_1)_x$

   $\overline{A}_{By} = \overline{A}_{Ay} + (\overline{\alpha}_1 \text{ X } \overline{r}_1)_y + \overline{W}_1 \text{ X } (\overline{W}_1 \text{ X } \overline{r}_1)_y$

4. To find $\overline{V}_C$ (wrist joint): $\overline{V}_C = \overline{V}_B + \overline{W}_2 \text{ X } \overline{r}_2$

   or $\overline{V}_{Cx} = \overline{V}_{Bx} + (\overline{W}_2 \text{ X } \overline{r}_2)_x$

   $\overline{V}_{Cy} = \overline{V}_{Cy} + (\overline{W}_2 \text{ X } \overline{r}_2)_y$

5. To find $\overline{A}_C$ (wrist joint): $\overline{A}_C = \overline{A}_B + \alpha_2 \text{ X } \overline{r}_2 + \overline{W}_2 \text{ X } (\overline{W}_2 \text{ X } \overline{r}_2)$

or $\overline{A}_{Cx} = \overline{A}_{Bx} + (\overline{\alpha}_2 \, X \, \overline{r}_2)_x + \overline{W}_2 \, X \, (\overline{W}_2 \, X \, \overline{r}_2)_x$

$\overline{A}_{Cy} = \overline{A}_{By} + (\overline{\alpha}_2 \, X \, \overline{r}_2)_y + \overline{W}_2 \, X \, \overline{r}_2)_y$

6. To find $\overline{V}_D$ (fingertips): $\overline{V}_D = \overline{V}_C = \overline{V}_C + \overline{W}_3 \, X \, \overline{r}_3$

or $\overline{V}_{Dx} = \overline{V}_{Cx} + (\overline{W}_3 \, X \, \overline{r}_3)_x$

$\overline{V}_{Dy} = \overline{V}_{Dy} + (\overline{W}_3 \, X \, \overline{r}_3)_y$

7. To find $\overline{A}_D$ (fingertips): $\overline{A}_D = \overline{A}_C + \overline{\alpha}_3 \, X \, \overline{r}_3 + \overline{W}_3 \, X \, (\overline{W}_3 \, X \, \overline{r}_3)$

or $\overline{A}_{Dx} = \overline{A}_{Cx} + \overline{W}_3 \, X \, \overline{r}_{3x} + \overline{W}_3 \, X \, (\overline{W}_3 \, X \, \overline{r}_3)_x$

$\overline{A}_{Dy} = \overline{A}_{Dy} + \overline{W}_3 \, X \, \overline{r}_{3y} + \overline{W}_3 \, X \, (\overline{W}_3 \, X \, \overline{r}_3)_y$

8. Using the above method, the Kinematics of the centers of gravity for each of the three segments were determined. The equations used were exactly the same as those listed above, except the magnitudes of the vectors r_1 , r_2, r_3 were altered to represent the distance to the C of G rather than the length of the segment.

KINETICS OF UPPER EXTREMITY MODEL

The upper extremity model was represented by free body diagrams of each of the three segments. The segments were assumed to be connected by hinge joints and friction at the joints was assumed to be negligible. The net forces and moments of force at each joint we calculated from the equations of Newtonian rigid-body mechanics. The general equations of motion are as follows: (Meriam, 1974: 240)

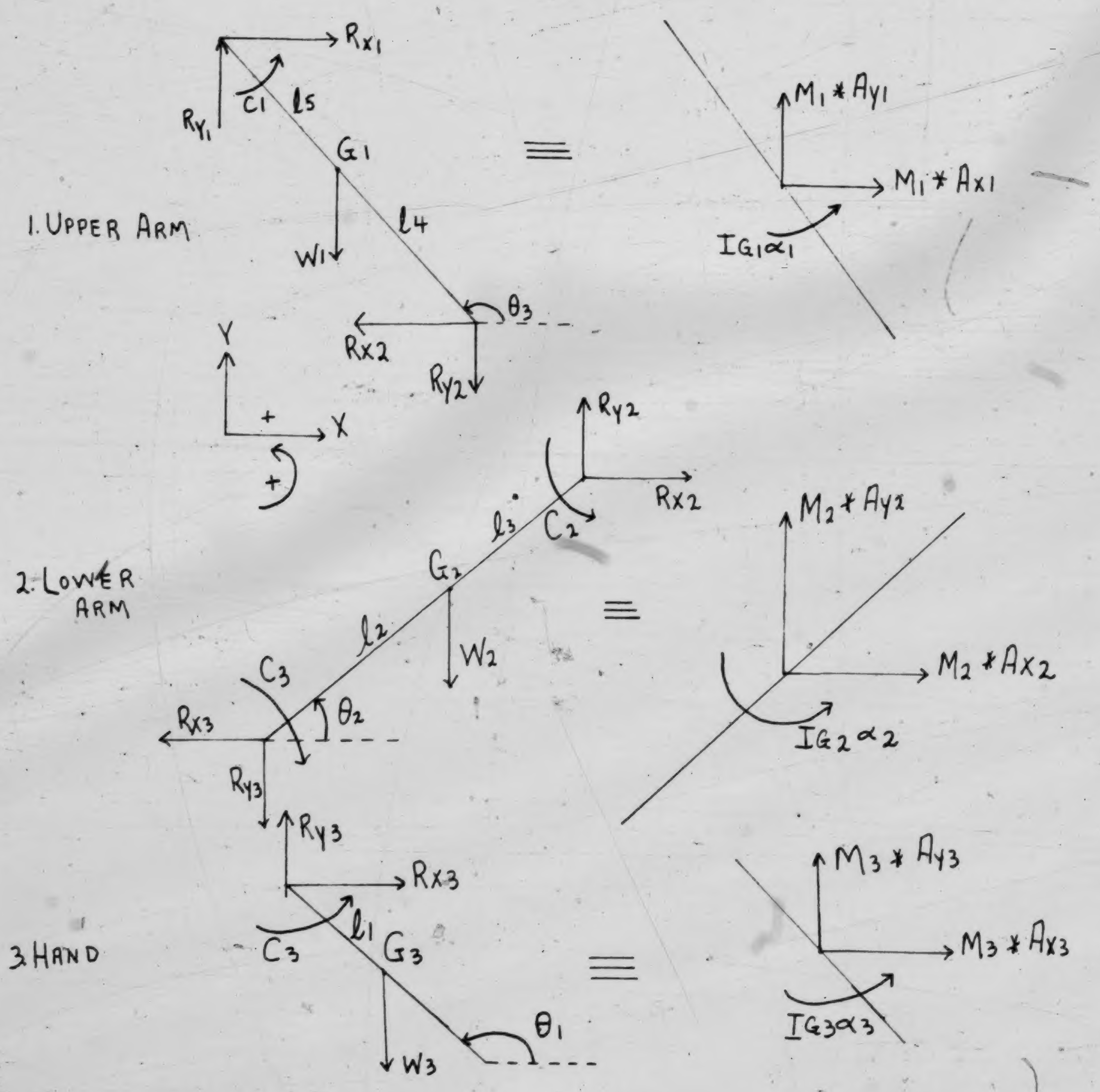
$$\Sigma F_x = M\,\bar{a}_x$$

$$\Sigma F_y = M\,\bar{a}_y$$

$$\Sigma M = I\alpha$$

For each rigid body, the sum of the forces, either horizontal (F_x) or vertical (F_y) was equivalent to the product of the mass of the segment (M) and the corresponding vertical or horizontal acceleration of the segment's center of mass. Similarly, the sum of the moments of force was equal to the product of the segment's angular acceleration and the appropriate mass moment of inertia (I) at the segment's center of mass.

Kinetic Equations of Upper Extremity


1. UPPER ARM
R_{x1}
R_{y1}
C1
l5
G1
W1
l4
θ_3
Rx2
R_{y2}
≡
$M_1 * A_{y1}$
$M_1 * A_{x1}$
$I_{G1}\alpha_1$
Y
X
+
+
2. LOWER ARM
R_{y2}
Rx2
l3
C_2
G_2
l2
W2
≡
$M_2 * A_{y2}$
$M_2 * A_{x2}$
$I_{G2}\alpha_2$
C_3
θ_2
Rx3
R_{y3}
3. HAND
R_{y3}
Rx3
C_3
l1
G_3
W3
θ_1
≡
$M_3 * A_{y3}$
$M_3 * A_{x3}$
$I_{G3}\alpha_3$

Equations of Motion of These Segments

Segment 3:

$$R_{x3} = M_3 \text{ X } A_{x3}$$

$$R_{y3} = M_3 \text{ X } A_{y3} + W_3$$

$$C_3 = I_{G3}\alpha_3 + (R_{x3} \text{ X } l_3 \text{ X Sin } \theta_1) + (R_{y3} \text{ X } l_3 \text{ X COS } \theta_1)$$

Segment 2:

$$R_{x2} = R_{x3} + M_2 \text{ X } A_{x2}$$

$$R_{y2} = R_{y3} + W_2 + M_2 \text{ X } A_{y2}$$

$$C_2 = C_3 + I_{G2}\alpha_2 - (R_{y2} \text{ X } l_3 \text{ X COS } \theta_2) + (R_{x2} \text{ X } l_3 \text{ X Sin } \theta_2) - (R_{y3} \text{ X } l_2 \text{ X COS } \theta_2) + (R_{x3} \text{ X } l_2 \text{ X COS } \theta_2)$$

Segment 1:

$$R_{x1} = R_{x2} + M_1 \text{ X } A_{x1}$$

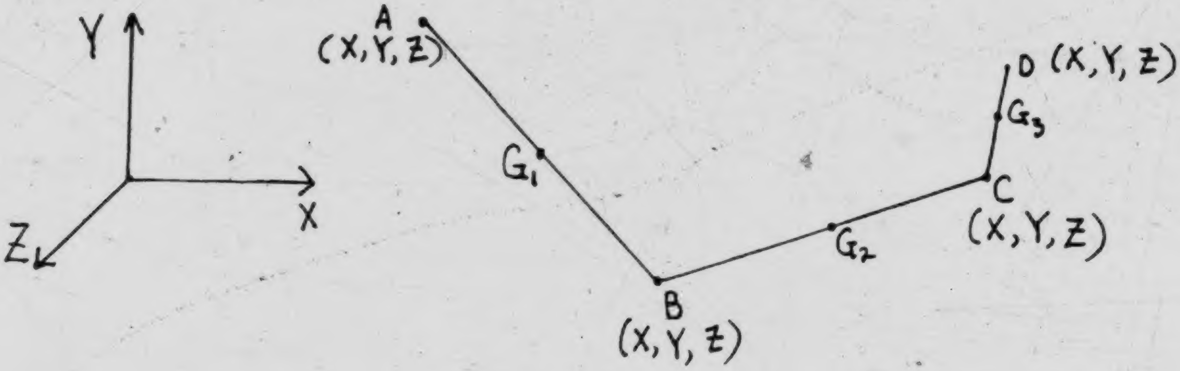
$$R_{y1} = R_{y2} + W_1 + M_1 \text{ X } A_{y1}$$

$$C_1 = C_2 + I_{G1}\alpha_1 + (R_{x1} \text{ X } l_5 \text{ X Sin } \theta_3) + (R_{y1} \text{ X } l_5 \text{ X COS } \theta_3) + (R_{y2} \text{ X } l_4 \text{ X COS } \theta_3) + (R_{x2} \text{ X } l_4 \text{ X Sin } \theta_3)$$

APPENDIX D

Equations for Three Dimensional Analyses

SAMPLE SEGMENT CALCULATION-TWO PLANE



1. Let $\overline{S}_A$ be the absolute linear displacement of point A over some time interval t. Then $\overline{S}_A$ may be divided into three components, in the X, Y, and Z directions. Each of these positions over several time periods may be plotted against time to form a displacement-time curve. This curve may then be differentiated once to produce velocity in the X, Y, or Z direction; and twice to produce acceleration in the X, Y, or Z direction.

2. Let $\overline{S}_B$ be the absolute linear displacement of point B (elbow joint) over some time interval t. From these displacements, the velocity and acceleration values may be determined in each of the 3 directions of interest.

3. This procedure may be continued for each of the segmental endpoints of interest.

ANALYSIS OF FOREARM ROTATIONS IN THE SOFTBALL PITCH

The objective of this analysis is to describe the magnitude of the forearm rotations with respect to the three principal axes of the forearm. This analysis will be described in terms of the steps taken in calculating these values using a FORTRAN computer program written by the present author. This technique of analysis is based on the assumption that there are accurate X, Y, and Z coordinates available for three distinct, non-colinear points on the forearm segment. These points must be clearly visible in the film record from both cameras used in filming the subject.

Step 1: To determine the total angular velocity of the forearm segment with respect to reference frame R in the various time intervals of interest, the X, Y, and Z coordinates of three points must be known. When the X, Y, and Z coordinates of a point have been determined over a time interval, the velocity over that interval may be determined. v_1 and v_2 are the relative linear velocities of points C and E with respect to B.

$$\text{Since } \bar{v}_1 = \bar{W} \times \bar{r}_1$$

$$\text{and } \bar{v}_2 = \bar{W} \times \bar{r}_2$$

Where $\bar{W}$ is the total angular velocity of the system, then the magnitude of $\bar{W}$ may be calculated from:

$$\overline{W} = \frac{\overline{v}_1 \times \overline{v}_2}{\overline{v}_1 \cdot \overline{r}_2} = \frac{\overline{v}_2 \times \overline{v}_1}{\overline{v}_2 \cdot \overline{r}_1}$$

Step 2: To determine the vectors $\overline{b}_1$ and $\overline{b}_3$ defining the reference frame in the forearm segment, the cross product of $\overline{c} \times \overline{d}$ must be formed. Since $\overline{b}_1$ is parallel to $\overline{c} \times \overline{d}$, then $\overline{c} \times \overline{d}$ can be divided by its length to form the unit vector $\overline{b_1}$.

The vector $\overline{b}_3$ may then be determined from $\overline{b}_3 = \overline{b}_1 \times \overline{b}_2$, since $\overline{b}_2$ is defined by the forearm segmental endpoints. The three unit vectors defining the reference frame in the forearm segment are as follows:

$$\overline{b_1} = b_{11}\overline{n}_1 + b_{12}\overline{n}_2 + b_{13}\overline{n}_3$$

$$\overline{b}_2 = b_{21}\overline{n}_1 + b_{22}\overline{n}_2 + b_{33}\overline{n}_3$$

$$\overline{b}_3 = b_{31}\overline{n}_1 + b_{32}\overline{n}_2 + b_{33}\overline{n}_3$$

Step 3: To determine the three components of the total rotation of the forearm (W) calculated in Step 1. The total rotation is

$$\overline{W} = W_1\overline{n}_1 + W_2\overline{n}_2 + W_3\overline{n}_3$$

A system of three equations in three unknowns may be formed from the above known quantities. For the case of a general vector k, where

$\overline{K} = k_1\overline{n}_1 + k_2\overline{n}_2 + k_3\overline{n}_3,$ then

$\overline{W} \cdot \overline{K} = W_1\overline{k}_1 + W_2\overline{k}_2 + W_3\overline{k}_3$

To apply this general case to the unit vectors forming the reference frame in the arm (Q), we have:

$$\overline{W} \cdot \overline{b}_1 = W_1 b_{11} + W_2 b_{12} + W_3 b_{13}$$

$$\overline{W} \cdot \overline{b}_2 = W_1 b_{21} + W_2 b_{22} + W_2 b_{23}$$

$$\overline{W} \cdot \overline{b}_3 = W_1 b_{31} + W_2 b_{32} + W_3 b_{33}$$

Where the three unknown quantities are W_1, W_2, and W_3. These symbols represent the following rotations:

$\overline{W}_1$ = flexion-extension at elbow joint

$\overline{W}_2$ = pronation-supination of the lower arm segment

$\overline{W}_3$ = abduction and adduction of the lower arm segment at the elbow joint.

The total rotation W in reference frame Q may be represented as:

$$\overline{W} = (\overline{W} \cdot \overline{b}_1)\overline{b}_1 + (\overline{W} \cdot \overline{b}_2)\overline{b}_2 + (\overline{W} \cdot \overline{b}_3)\overline{b}_3$$

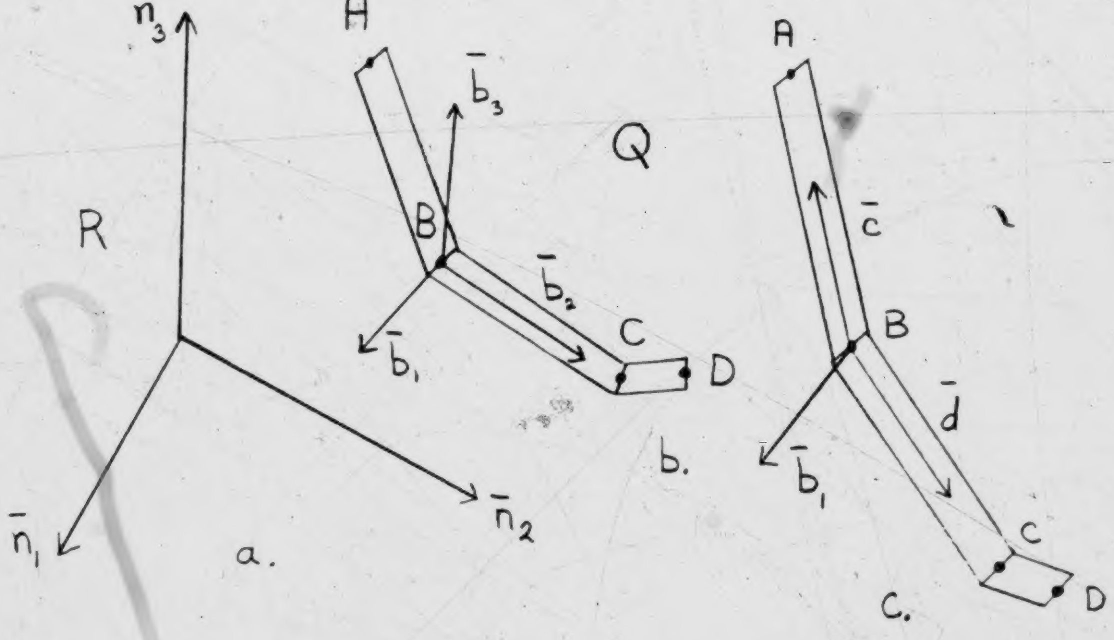

$\bar{n}_3$
$\bar{n}_1$
$\bar{n}_2$
R
a.
A
B
C
D
Q
$\bar{b}_3$
$\bar{b}_2$
$\bar{b}_1$
b.
A
$\bar{c}$
B
$\bar{d}$
$\bar{b}_1$
C
D
c.

Figure 64. Reference frames of Arm Segments

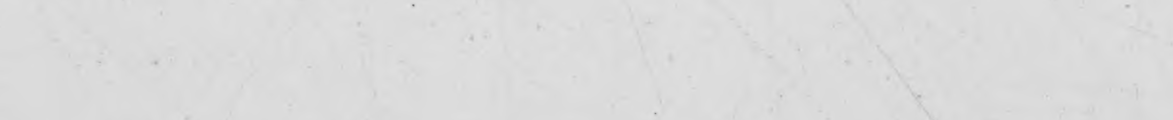

B
(X_B, Y_B, Z_B)
$\bar{r}_1$
$\bar{r}_2$
$C\ (X_C, Y_C, Z_C)$
$E\ (X_E, Y_E, Z_E)$

Figure 65. Points on Lower Arm Segment

APPENDIX E

Computer Program for Segmental Analysis

```
MTS  FORTRAN IV G COMPILER (O/S REL 21.8)          MAIN        06-17-78    23:02:43         PAGE 0001
C THREE SEGMENT ANALYSIS PROGRAM
C  WRITTEN BY MARION ALEXANDER, U OF ALBERTA, SPRING 1978
C PROGRAM WRITTEN TO ANALIZE THE KINETIC AND KINEMATIC
C  MOTION PARAMETERS OF THE THREE SEGMENTS OF THE ARM
C  DURING THE SKILL OF SOFTBALL PITCHING
          REAL X,F,DF,SM,Y,C,WK,LAL
          REAL M1,M3,M2,AG,IG1,IG2,IG3
          DIMENSION SMX(25),SMY(25),DS(25),YSX(25),YSY(25),CX(24,3),
       $ CY(24,3),DDS(25),DISX(25),DISY(25),DDDS(25)
          DIMENSION VELX(25),VELY(25),ACCX(25),ACCY(25)
            DIMENSION ALPHA(20),ALPH(20),ALP(20),AL(20),ALPH2(20)
          DIMENSION ALPH8(20),ALPH9(20)
          DIMENSION ALPH3(20),ALPH4(20),ALPH5(20),ALPH6(20),ALPH7(20)
          DIMENSION RX1(25),RY1(25),RX2(25),RY2(25),RX3(25),RY3(25),
       $ C1(25),C2(25),C3(25)
          DIMENSION XIIG(25),YJJG(25),XIAG(25),YJAG(25),XI2G(25),YJ2G(25)
       $ ,XIA2G(25),YJA2G(25),XI3G(25),YJ3G(25),XIA3G(25),YJA3G(25)
          DIMENSION DISP (25),VEL (25),ACC (25),WK(2000)
          DIMENSION DISP2(25),VEL2(25),ACC2(25),DISP3(25)
          DIMENSION VEL3(25),ACC3(25)
          DIMENSION G(25),H(25),YY(25),YYY(25),XI(25),YJ(25)
          DIMENSION XIA(25),YJA(25),XI2(25),YJ2(25),XIA2(25),YJA2(25)
          DIMENSION XI3(25),YJ3(25),XIA3(25),YJA3(25)
          DIMENSION XII(25),YJJ(25),THETA(25)
          DIMENSION X (25),F (25),DF (25),Y(24),C(24,3)
          DIMENSION CC(24,3),CCC(24,3)
          IOU=6
C READ IN MASSES OF 3 SEGMENTS AND THEIR MOMENTS OF INERTIA
          READ(5,502)M1,M2,M3,IG1,IG2,IG3
502       FORMAT(6F10.5)
C  READ IN LENGTHS OF EACH OF THE SEGMENTS
          READ(5,502)UAL,LAL,HL
503       FORMAT(3F10.5)
          AG=9.814
          SL1=UAL*.436
          SL2=LAL*.43
          SL3=HL*.28
          W1=M1*AG
          W2=M2*AG
          W3=M3*AG
          IZ=25
          IC=24
           SM=25.0
           READ(5,501)(ALPHA(I),I=1,20)
501        FORMAT(20A4)
          READ(5,501)(ALP(I),I=1,20)
          READ(5,501)(AL(I),I=1,20)
          READ(5,501)(ALPH(I),I=1,20)
          READ(5,501)(ALPH2(I),I=1,20)
          READ(5,501)(ALPH3(I),I=1,20)
          READ(5,501)(ALPH4(I),I=1,20)
          READ(5,501)(ALPH5(I),I=1,20)
          READ(5,501)(ALPH6(I),I=1,20)
          READ(5,501)(ALPH7(I),I=1,20)
          NX=25
```

```
MTS  FORTRAN IV G COMPILER (O/S REL 21.8)            MAIN         06-17-78     23:02:43          PAGE 0002
    56.000     0046              READ(5,501) (ALPH8(I),I=1,20)
    57.000     0047              READ(5,501) (ALPH9(I),I=1,20)
    58.000                 C  READ IN THE DEGREE OF SMOOTHING TO OCCUR IN THE SPLINE ROUTINE
    59.000                 C  WHERE FF IS THE DEGREE OF SMOOTHING FOR THE UPPER ARM SEGMENT
    60.000                 C AND DSZ IS THE DEGREE OF SMOOTHING FOR THE  LOWER ARM SEGMENT
    61.000                 C  AND DSS IS THE DEGREE OF SMOOTHING FOR THE SEG ENDPOINTS
    62.000                 C AND DSY IS THE DEGREE OF SMOOTHING FOR THE HAND SEGMENT
    63.000     0048              READ(5,51) FF,DSS,DSY,DSZ
    64.000     0049        51    FORMAT(4F10.5)
    65.000                 C READ IN THE MINIMUM VALUES OF PARAMETERS TO BE GRAPHED
    65.200                 C  WHERE DY3 IS THE MINIMUM ANG DISPL OF HAND
    65.400                 C AND DY2 IS THE MIN ANG DISPL OF THE LOWER ARM
    65.600                 C  AND DY1 IS THE MIN ANG DISPL OF THE UPPER ARM
    65.650                 C  WHERE A3 IS THE MINIMUM ANG ACCEL OF THE HAND
    65.700                 C  AND A2 IS THE MIN ANG ACCEL OF THE LOWER ARM
    65.750                 C  AND A1 IS THE MIN ANG ACCEL OF THE UPPER ARM
    66.000     0050              READ(5,561)DY3,DY2,DY1,A3,A2,A1
    67.000     0051        561   FORMAT(6F10.5)
    68.000                 C  READ IN THE LINEAR KINEMATIC PARAMETERS TO BE GRAPHED
    68.100                 C  WHERE VFX IS THE MINIMUM X-VEL OF THE FINGERS
    68.200                 C  AND VFY IS THE MIN Y-VEL OF THE FINGERS
    68.300                 C  AND AFX IS THE MIN X-ACCEL OF THE FINGERS
    68.400                 C  AND AFY IS THE MIN Y-ACCEL OF THE FINGERS
    69.000     0052              READ(5,562) VFX,VFY,AFX,AFY
    70.000     0053        562   FORMAT(4F10.4)
    71.000     0054              READ(5,562) RFX,RFY,CM1,CM2
    72.000                 C AND THEN READ IN THE KINETIC PARAMETERS TO BE GRAPHED
    72.100                 C  WHERE RFX IS THE MINIMUM X-FORCE AT SHOULDER
    72.200                 C  AND RFY IS THE MINIMUM Y-FORCE AT SHOULDER
    72.300                 C  AND CM1 IS THE MINIMUM TIME FOR THE MOMENT CURVES
    72.400                 C  AND CM2 IS THE MIN VALUE FOR THE SHOULDER MOMENT
    73.000     0055              RAD=57.29577
    74.000     0056              DO 2 I=1,NX
    75.000     0057              READ(5,3) X(I),F(I),G(I),H(I),SHX(I),SHY(I)
    76.000     0058        3      FORMAT(6F10.5)
    77.000     0059              DF(I)=FF
    78.000     0060              DS(I)=DSS
    79.000     0061              DDS(I)=DSY
    80.000     0062              DDDS(I)=DSZ
    81.000                 C  CHANGE DISPLACEMENTS IN DEGREES TO RADIANS
    82.000     0063              F(I)=F(I)/RAD
    83.000     0064              G(I)=G(I)/RAD
    84.000     0065              H(I)=H(I)/RAD
    85.000     0066        2      CONTINUE
    86.000     0067              M=NX-1
    87.000     0068              CALL ICSSCU(X,SHX,DS,NX,SM,YSX,CX,IC,WK,IER)
    88.000     0069              CALL ICSSCU(X,SHY,DS,NX,SM,YSY,CY,IC,WK,IER)
    89.000     0070              CALL ICSSCU(X,F,DF,NX,SM,Y,C,IC,WK,IER)
    90.000     0071              CALL ICSSCU(X,G,DDDS,NX,SM,YY,CC,IC,WK,IER)
    91.000     0072              CALL ICSSCU(X,H,DDS,NX,SM,YYY,CCC,IC,WK,IER)
    92.000     0073              DO 4 I=1,M
    93.000     0074              DISX(I)=YSX(I)
    94.000     0075              DISY(I)=YSY(I)
    95.000     0076              VELX(I)=CX(I,1)
    96.000     0077              VELY(I)=CY(I,1)
    97.000      0078                 ACCX(I)=2.*CX(I,2)
    98.000      0079                 ACCY(I)=2.*CY(I,2)
    99.000      0080                 DISP(I)=Y(I)
   100.000      0081                 DISP2(I)=YY(I)
   101.000      0082                 VEL2(I)=CC(I,1)
   102.000      0083                 ACC2(I)=2.*CC(I,2)
   103.000      0084                 DISP3(I)=YYY(I)
   104.000      0085                 VEL3(I)=CCC(I,1)
   105.000      0086                 ACC3(I)=2.*CCC(I,2)
   106.000      0087                 VEL(I)=C(I,1)
   107.000      0088                 ACC(I)=2.*C(I,2)
   108.000      0089           4      CONTINUE
   109.000      0090                 WRITE(6,15)
   110.000      0091          15       FORMAT('1',30X,'SEGMENTAL ANALYSIS PROGRAM-3 SEGMENTS')
   111.000      0092                 WRITE(6,555)
   112.000      0093         555      FORMAT(' -',30X,'ANGULAR KINEMATICS OF THE UPPER ARM')
   113.000      0094                 WRITE(6,6)
   114.000      0095           6      FORMAT('0',10X,'INPUT',50X,'OUTPUT')
   115.000      0096                 WRITE(6,7)
   116.000      0097           7      FORMAT('0',5X,'X',10X,'F',10X,'TIME',8X,'DISPLACEMENT',
   117.000                          *6X,'VELOCITY',8X,'ACCELERATION')
   118.000      0098                 DO 8 I=1,N
   119.000      0099           8     WRITE(6,9)  X(I),F(I),Y(I),DISP(I),VEL(I),ACC(I)
   120.000      0100                 WRITE(6,500) (ALPH7(I),I=1,20)
   121.000      0101         500      FORMAT(//,20A4)
   122.000      0102                 WRITE(6,15)
   123.000      0103                 WRITE(6,556)
   124.000      0104         556     FORMAT('-',30X,'ANGULAR KINEMATICS OF THE LOWER ARM')
   125.000      0105                 WRITE(6,6)
   126.000      0106                 WRITE(6,7)
   127.000      0107                 DO 13 I=1,N
   128.000      0108          13     WRITE(6,9)  X(I),G(I),Y(I),DISP2(I),VEL2(I),ACC2(I)
   129.000      0109                 WRITE(6,500) (ALPH7(I),I=1,20)
   130.000      0110                 WRITE(6,15)
   131.000      0111                 WRITE(6,557)
   132.000      0112         557     FORMAT('-',30X,'ANGULAR KINEMATICS OF THE HAND SEGMENT')
   133.000      0113                 WRITE(6,6)
   134.000      0114                 WRITE(6,7)
   135.000      0115                 DO 14 I=1,N
   136.000      0116          14      WRITE(6,9)  X(I),H(I),Y(I),DISP3(I),VEL3(I),ACC3(I)
   137.000      0117                 WRITE(6,500) (ALPH7(I),I=1,20)
   138.000      0118                 WRITE(6,666)
   139.000      0119         666     FORMAT('1',30X,'LINEAR KINEMATICS OF SHOULDER '//)
   140.000      0120                 WRITE(6,6)
   141.000      0121                 WRITE(6,7)
   142.000      0122           9      FORMAT(3X,F5.3,5X,F7.3,6X,F5.3,3(6X,F12.4))
   143.000      0123                 WRITE(6,558)
   144.000      0124         558      FORMAT('0',30X,'X-COORDINATES OF SHOULDER')
   145.000      0125                 DO 18 I=1,N
   146.000      0126          18     WRITE(6,9)Y(I),SHX(I),X(I),DISX(I),VELX(I),ACCX(I)
   147.000      0127                 WRITE(6,500) (ALPH7(I),I=1,20)
   147.200      0128                 WRITE(6,666)
   147.400      0129                 WRITE(6,6)
   147.600      0130                 WRITE(6,7)
   148.000      0131                 WRITE(6,559)
```

```
559     FORMAT('0',30X,'Y-COORDINATES OF SHOULDER')
        DO 19 I=1,M
 19     WRITE(6,9)I(I),SHY(I),X(I),DIST(I),VELY(I),ACCY(I)
        WRITE(6,500)(ALPH7(I),I=1,20)
C  CALCULATE LINEAR VELOCITIES
C  INSERT TRUE LENGTHS OF LIMB SEGMENTS
C  VA IS LINEAR VEL OF SHOULDER JOINT
C  VB IS LINEAR VEL OF ELBOW JOINT
C  VC IS LINEAR VEL OF WRIST
C  VD IS LINEAR VEL OF FINGERTIPS
C  VECTOR NOTATION FOR THE THREE VECTORS IS XI,YJ,ZK
        WRITE(6,24)
24      FORMAT('1',15X,'LINEAR VELOCITIES AND ACCELERATIONS OF SEGMENTAL
     $  ENDPOINTS')
        WRITE(6,25)
25      FORMAT(//,40X,'ELBOW KINEMATICS',//)
        WRITE(6,23)
23      FORMAT(' FRAME',4X,'X-VELOCITY',10X,'Y-VELOCITY',10X,
     6'X-ACCELERATION',6X,'Y-ACCELERATION')
C  CALCULATE VELOCITY AND ACCELERATION COMPONENTS OF THE ELBOW
        CALL VECTOR(DISP,UAL,XI,YJ)
        DO 5 I=1,M
        XII(I)=VEL(I)*(-YJ(I))+VELX(I)
        YJJ(I)=VEL(I)*(XI(I))+VELY(I)
        XIA(I)=(ACC(I)*(-YJ(I)))+(VEL(I)*(-YJJ(I)))+ACCX(I)
        YJA(I)=(ACC(I)*XI(I))+(VEL(I)*XII(I))+ACCY(I)
        WRITE(6,27)I,XII(I),YJJ(I),XIA(I),YJA(I)
 5      CONTINUE
        WRITE(6,500)(ALPH7(I),I=1,20)
C CALCULATE VELOCITY AND ACCELERATION COMPONENTS OF THE ARM COFG
        WRITE(6,24)
        WRITE(6,56)
56      FORMAT('-',30X,'KINEMATICS OF THE ARM CENTER OF GRAVITY',//)
        WRITE(6,23)
        CALL VECTOR(DISP,SL1,XI,YJ)
       DO 55 I=1,M
        XIIG(I)=VEL(I)*(-YJ(I))+VELX(I)
        YJJG(I)=VEL(I)*(XI(I))+VELY(I)
        XIAG(I)=(ACC(I)*(-YJ(I)))+(VEL(I)*(-YJJ(I)))+ACCX(I)
        YJAG(I)=(ACC(I)*XI(I))+(VEL(I)*XII(I))+ACCY(I)
        WRITE(6,27)I,XIIG(I),YJJG(I),XIAG(I),YJAG(I)
55      CONTINUE
        WRITE(6,500)(ALPH7(I),I=1,20)
27     FORMAT(I5,5X,3(F10.4,10X),F10.4)
C  CALCULATE VELOCITY AND ACCELERATION COMPONENTS OF THE WRIST
        WRITE(6,24)
        WRITE(6,28)
28      FORMAT('-',40X,'WRIST KINEMATICS',//)
        WRITE(6,23)
        CALL VECTOR(DISP2,LAL,XI,YJ)
        DO 43 I=1,M
        XI2(I)=VEL2(I)*(-YJ(I))+XII(I)
        YJ2(I)=VEL2(I)*(XI(I))+YJJ(I)
        XIA2(I)=(ACC2(I)*(-YJ(I)))+(VEL2(I)*(-YJ2(I)))+XIA(I)
       YJA2(I)=(ACC2(I)*XI(I))+(VEL2(I)*XI2(I))+YJA(I)
 203.000    0175                  WRITE(6,27)I,XI2(I),YJ2(I),XIA2(I),YJA2(I)
 205.000    0176           43     CONTINUE
 205.500    0177                  WRITE(6,500) (ALPH7(I),I=1,20)
 206.000                C CALCULATE VELOCITY AND ACCELERATION COMPONENTS OF THE L ARM COFG
 207.000    0178                  WRITE(6,24)
 208.000    0179                  WRITE(6,92)
 209.000    0180           92     FORMAT('-',30X,'KINEMATICS OF THE LOWER ARM CENTER OF GRAVITY',//)
 210.000    0181                  WRITE(6,23)
 211.000    0182                  CALL VECTOR(DISP2,SL2,XI,YJ)
 212.000    0183                  DO 96 I=1,N
 213.000    0184                  XI2G(I)=VEL2(I)*(-YJ(I))+XII(I)
 214.000    0185                  YJ2G(I)=VEL2(I)*(XI(I))+YJJ(I)
 215.000    0186                  XIA2G(I)=(ACC2(I)*(-YJ(I)))+(VEL2(I)*(-YJ2(I)))+XIA(I)
 216.000    0187                 YJA2G(I)=(ACC2(I)*XI(I))+(VEL2(I)*XI2(I))+YJA(I)
 217.000    0188                  WRITE(6,27)I,XI2G(I),YJ2G(I),XIA2G(I),YJA2G(I)
 219.000    0189            96    CONTINUE
 219.500    0190                  WRITE(6,500) (ALPH7(I),I=1,20)
 220.000                C CALCULATE VELOCITY AND ACCEL OF FINGERTIPS--VD
 221.000    0191                  WRITE(6,24)
 222.000    0192                  CALL VECTOR(DISP3,SL,XI,YJ)
 223.000    0193                  WRITE(6,29)
 224.000    0194           29     FORMAT('-',40X,'FINGERTIP KINEMATICS',//)
 225.000    0195                  WRITE(6,23)
 226.000    0196                  DO 44 I=1,N
 227.000    0197                  XI3(I)=(VEL3(I)*(-YJ(I)))+XI2(I)
 228.000    0198                  YJ3(I)=(VEL3(I)*(XI(I)))+YJ2(I)
 229.000    0199                  XIA3(I)=(ACC3(I)*(-YJ(I)))+(VEL3(I)*(-YJ3(I)))+XIA2(I)
 230.000    0200                  YJA3(I)=(ACC3(I)*XI(I))+(VEL3(I)*XI3(I))+XIA2(I)
 231.000    0201                  WRITE(6,27)I,XI3(I),YJ3(I),XIA3(I),YJA3(I)
 233.000    0202           44     CONTINUE
 233.500    0203                  WRITE(6,500) (ALPH7(I),I=1,20)
 234.000                C CALCULATION OF THE HAND COFG KINEMATICS
 235.000    0204                  WRITE(6,24)
 236.000    0205                  WRITE(6,99)
 237.000    0206           99     FORMAT('-',30X,'KINEMATICS OF THE HAND CENTER OF GRAVITY',//)
 238.000    0207                  WRITE(6,23)
 239.000    0208                  CALL VECTOR(DISP3,SL3,XI,YJ)
 240.000    0209                  DO 98 I=1,N
 241.000    0210                  XI3G(I)=(VEL3(I)*(-YJ(I)))+XI2(I)
 242.000    0211                  YJ3G(I)=(VEL3(I)*(XI(I)))+YJ2(I)
 243.000    0212                  XIA3G(I)=(ACC3(I)*(-YJ(I)))+(VEL3(I)*(-YJ3(I)))+XIA2(I)
 244.000    0213                  YJA3G(I)=(ACC3(I)*XI(I))+(VEL3(I)*XI3(I))+XIA2(I)
 245.000    0214                  WRITE(6,27)I,XI3G(I),YJ3G(I),XIA3G(I),YJA3G(I)
 247.000    0215           98     CONTINUE
 247.500    0216                  WRITE(6,500) (ALPH7(I),I=1,20)
 248.000                C CALCULATION OF THE JOINT FORCES AND MOMENTS FOR EACH FRAME
 249.000    0217                  DO 90 I=1,N
 250.000                C  CALCULATIONS FOR SEGMENT 3--THE HAND
 251.000    0218                  RX3(I)=M3*XIA3G(I)
 252.000    0219                  RY3(I)=W3+M3*YJA3(I)
 253.000    0220                  C3(I)=IG3*ACC3(I)+RX3(I)*SL3*SIN(DISP3(I))+RY3(I)*SL3*
 254.000                     $ COS(DISP3(I))
 255.000                C  CALCULATIONS FOR SEGMENT 2=THE LOWER ARM SEGMENT
 256.000    0221                  RX2(I)=RX3(I)+M2*XIA2G(I)
 257.000    0222                  RY2(I)=RY3(I)+W2+M2*YJA2G(I)
```

```
MTS  FORTRAN IV G COMPILER (O/S REL 21.8)                    MAIN        06-17-78    23:02:43         PAGE 0006
  258.000     0223                C2(I)=IG2*ACC2(I)+(RX2(I)*S2*SIN(DISP2(I)))-(RY2(I)*S2*
  259.000                       $ COS(DISP2(I)))
  260.000                       $ +C3(I)+(RX3(I)*(LAL-S2)*SIN(DISP2(I)))-(RY3(I)*(LAL-S2)*
  261.000                       $ COS(DISP2(I)))
  262.000                 C CALCULATIONS FOR SEGMENT 1--THE UPPER ARM SEGMENT
  263.000     0224                RX1(I)=RX2(I)+M1*XIAG(I)
  264.000     0225                RY1(I)=RY2(I)+M1*YJAG(I)
  265.000     0226                C1(I)=C2(I)+IG1*ACC(I)+(RX2(I)*(UAL-SL1)*SIN(DISP(I)))+
  266.000                       $ (RY2(I)*(UAL-SL1)*
  267.000                       $ COS(DISP(I)))+(RX1(I)*SL1*SIN(DISP(I)))+(RY1(I)*SL1*COS(DISP(I)))
  268.000     0227        90      CONTINUE
  269.000     0228                WRITE(6,81)
  270.000     0229        81      FORMAT('1',20X,'KINETICS OF THE UPPER EXTREMITY'//)
  271.000     0230                WRITE(6,85)
  272.000     0231        85       FORMAT(20X,'FORCES AND MOMENTS AT THE WRIST JOINT'//)
  273.000     0232                WRITE(6,84)
  274.000     0233        84      FORMAT(2X,'FRAME',3X,'X-JOINT FORCES',3X,'Y-JOINT FORCES',
  275.000                       $ 5X,'MOMENT AT THE JOINT')
  276.000     0234                DO 82 I=1,M
  277.000     0235        82      WRITE(6,83)I,RX3(I),RY3(I),C3(I)
  278.000     0236                WRITE(6,500)(ALPH7(I),I=1,20)
  279.000     0237        83      FORMAT(I5,3(5X,F15.5))
  280.000     0238                WRITE(6,81)
  281.000     0239                WRITE(6,88)
  282.000     0240        88      FORMAT('-',20X,'FORCES AND MOMENTS AT THE ELBOW JOINT',//)
  283.000     0241                WRITE(6,84)
  284.000     0242                DO 86 I=1,M
  285.000     0243        86      WRITE(6,83)I,RX2(I),RY2(I),C2(I)
  286.000     0244                WRITE(6,500)(ALPH7(I),I=1,20)
  287.000     0245                WRITE(6,81)
  288.000     0246                WRITE(6,89)
  289.000     0247        89      FORMAT('-',20X,'FORCES AND MOMENTS AT THE SHOULDER JOINT',//)
  290.000     0248                WRITE(6,84)
  291.000     0249                DO 87 I=[illegible]
  292.000     0250        87      WRITE(6,83)I,RX1(I),RY1(I),C1(I)
  293.000     0251                WRITE(6,500)(ALPH7(I),I=1,20)
  294.000     0252                WRITE(6,560)
  295.000     0253        560     FORMAT('1')
  296.000                 C       CALL CGPEP1 (1.0,1.0)
  297.000                 C  GRAPHS OF X AND Y LINEAR VELOCITIES VS. TIME
  298.000                 C FOR THE FOUR SEGMENTAL ENDPOINTS OF THE ARM
  299.000     0254                CALL CGPL(X,XI3,X,M,1,1,1,3,2,0.,-9.9,4.0,VPX,
  300.000                     $ -9.9,4.0,ALPH9,IOU)
  301.000     0255                CALL CGPL(X,YJ3,X,M,2,1,1,3,2,0.,-9.9,4.0,VPY,
  302.000                     $ -9.9,4.0,ALPH9,IOU)
  303.000     0256                CALL CGPL(X,XI2,X,M,1,1,1,3,2,0.,-9.9,4.0,VPX,
  304.000                     $ -9.9,4.0,ALPH8,IOU)
  305.000     0257                CALL CGPL(X,YJ2,X,M,2,1,1,3,2,0.,-9.9,4.0,VPY,
  306.000                     $ -9.9,4.0,ALPH8,IOU)
  307.000     0258                CALL CGPL(X,XI1,X,M,1,1,1,3,2,0.,-9.9,4.0,VPX,
  308.000                     $ -9.9,4.0,ALPH5,IOU)
  309.000     0259                CALL CGPL(X,YJ1,X,M,2,1,1,3,2,0.,-9.9,4.0,VPY,
  310.000                     $ -9.9,4.0,ALPH5,IOU)
  311.000     0260                CALL CGPL(X,VELX,X,M,1,1,1,3,2,0.,-9.9,4.0,VPX,
  312.000                     $ -9.9,4.0,ALPH4,IOU)
```

```
 313.000    0261              CALL CGPL(X,VELY,X,F,2,1,1,3,2,0.,-9.9,8.0,VPY,
 314.000                    $ -9.9,8.0,ALPH4,IOU)
 314.200                C GRAPH OF ANGULAR DISPLACEMENT VS. TIME--3 SEGS
 315.000    0262              CALL CGPL(X,DISP3,H,M,1,1,1,3,2,0.,-9.9,6.0,DY3,
 316.000                    $ -9.9,8.0,ALPHA,IOU)
 319.000    0263              CALL CGPL(X,DISP2,G,M,2,1,1,3,2,0.,-9.9,6.0,DY2,
 320.000                    $ -9.9,8.0,ALPHA,IOU)
 321.000    0264              CALL CGPL(X,DISP,F,M,3,1,1,3,2,0.,-9.9,6.0,DY1,-9.9,8.0,ALPHA,
 322.000                    $ IOU)
 322.200                C  GRAPHS OF ANGULAR VELOCITY VS TIME 3 SEGS
 323.000    0265              CALL CGPL(X,VEL3,H,M,1,1,1,3,2,0.,-9.9,6.0,0.0,
 324.000                    $ -9.9,8.0,ALP,IOU)
 325.000    0266              CALL CGPL(X,VEL2,G,M,2,1,1,3,2,0.,-9.9,6.0,0.0,
 326.000                    $ -9.9,8.0,ALP,IOU)
 327.000    0267              CALL CGPL(X,VEL,F,M,3,1,1,3,2,0.,-9.9,6.0,0.0,-9.9,8.0,ALP,
 328.000                    $ IOU)
 328.200                C  GRAPHS OF ANGULAR ACCELERATION VS. TIME 3 SEGS
 329.000    0268              CALL CGPL(X,ACC3,H,M,1,1,1,3,2,0.,-9.9,6.0,A3,
 330.000                    $ -9.9,8.0,AL,IOU)
 331.000    0269              CALL CGPL(X,ACC2,G,M,2,1,1,3,2,0.,-9.9,6.0,A2,
 332.000                    $ -9.9,8.0,AL,IOU)
 333.000    0270              CALL CGPL(X,ACC,F,M,3,1,1,3,2,0.,-9.9,6.0,A1,
 334.000                    $ -9.9,8.0,AL,IOU)
 334.200                C  GRAPHS OF LINEAR VELOCITIES X VS. Y FOR EACH SEG
 335.000    0271              CALL CGPL(XI3,YJ3,X,M,1,1,1,3,2,VPX,-9.9,6.0,VPY,-9.9,8.0,ALPH,
 336.000                    $ IOU)
 337.000    0272              CALL CGPL(XI2,YJ2,X,M,2,1,1,3,2,VPX,-9.9,6.0,VPY,-9.9,8.0,ALPH,
 338.000                    $ IOU)
 339.000    0273              CALL CGPL(XI1,YJ1,X,M,3,1,1,3,2,VPX,-9.9,6.0,VPY,-9.9,8.0,ALPH,
 340.000                    $ IOU)
 341.000    0274              CALL CGPL(VELX,VELY,X,M,4,1,1,3,2,VPX,-9.9,6.0,VPY,
 342.000                    $ -9.9,8.0,ALPH,IOU)
 342.200                C  GRAPHS OF LINEAR ACCELERATIONS X VS. Y FOR SEGS
 343.000    0275              CALL CGPL(XIA3,YJA3,X,M,1,1,1,3,2,APX,-9.9,6.0,APY,
 344.000                    $ -9.9,8.0,ALPH2,IOU)
 345.000    0276              CALL CGPL(XIA2,YJA2,X,M,2,1,1,3,2,APX,-9.9,6.0,APY,
 346.000                    $ -9.9,8.0,ALPH2,IOU)
 347.000    0277              CALL CGPL(XIA,YJA,X,M,3,1,1,3,2,APX,-9.9,6.0,APY,
 348.000                    $ -9.9,8.0,ALPH2,IOU)
 349.000    0278              CALL CGPL(ACCX,ACCY,X,M,4,1,1,3,2,APX,-9.9,6.0,APY,
 350.000                    $ -9.9,8.0,ALPH2,IOU)
 351.000    0279              CALL CGPL(RX1,RY1,X,M,1,1,1,3,2,RPX,-9.9,6.0,RPY,
 351.200                C  GRAPHS OF RESULTANT FORCES AT THE JOINTS
 352.000                    $ -9.9,8.0,ALPH3,IOU)
 353.000    0280              CALL CGPL(RX2,RY2,X,M,2,1,1,3,2,RPX,-9.9,6.0,RPY,
 354.000                    $ -9.9,8.0,ALPH4,IOU)
 355.000    0281              CALL CGPL(RX3,RY3,X,M,3,1,1,3,2,RPX,-9.9,6.0,RPY,
 356.000                    $ -9.9,8.0,ALPH3,IOU)
 356.200                C  GRAPHS OF RESULTANT COUPLES AT THE JOINTS
 357.000    0282              CALL CGPL(X,C1,H,M,1,1,1,3,2,CM1,-9.9,6.0,CM2,
 358.000                    $ -9.9,8.0,ALPH6,IOU)
 359.000    0283              CALL CGPL(X,C2,H,M,2,1,1,3,2,CM1,-9.9,6.0,CM2,
 360.000                    $ -9.9,8.0,ALPH6,IOU)
 361.000    0284              CALL CGPL(X,C3,G,M,3,1,1,3,2,CM1,-9.9,8.0,CM2,
 362.000                    $ -9.9,8.0,ALPH7,IOU)
```

```
MTS  FORTRAN IV G COMPILER (O/S REL 21.8)              VECTOR      06-17-75     23:02:47        PAGE 0001

   367.000      0001                     SUBROUTINE VECTOR(P,XL,X,Y)
   368.000      0002                     DIMENSION P(25),X(25),Y(25),Z(25),THETA(25)
   369.000      0003                     DO 11 I=1,25
   370.000      0004                     Y(I)=0.0
   371.000      0005           11        X(I)=0.0
   372.000      0006                     DO 3 I=1,25
   373.000      0007                     THETA(I)=P(I)
   374.000      0008                     X(I)=XL*COS(THETA(I))
   375.000      0009                     Y(I)=XL*SIN(THETA(I))
   376.000      0010           3          CONTINUE
   377.000      0011                     RETURN
   378.000      0012                     END
```

```
MTS  FORTRAN IV G COMPILER (O/S REL 21.8)              MAIN        06-17-75     23:02:43        PAGE 0008

   363.000      0285                     CALL CGPL(X,DISP,P,N,0,1,1,3,2,0.,-9.9,6.0,-1.25,-9.9,6.0,ALPHA,
   364.000                             3 IOU)
   365.000      0286                     STOP
   366.000      0287                     END
```

APPENDIX F

Computer Program for Angular Velocities

```
MTS  FORTRAN IV G COMPILER (O/S REL 21.8)              MAIN        06-29-78    08:56:23         PAGE 0001

     1.000                  C COMPUTER PROGRAM TO DETERMINE MAGNITUDES OF FOREARM ROTATIONS
     2.000       0001             DIMENSION XA(20),XB(20),XC(20),XD(20),XE(20)
     3.000       0002             DIMENSION YA(20),YB(20),YC(20),YD(20),YE(20),
     4.000                       $ ZA(20),ZB(20),ZC(20),ZD(20),ZE(20),XC1(20,3),
     5.000                       $ YC1(20,3),ZC1(20,3),XC2(20,3),YC2(20,3),ZC2(20,3),
     6.000                       $ XC3(20,3),YC3(20,3),ZC3(20,3),VELXB(20),VELYB(20),
     7.000                       $VELZB(20),VELXC(20),VELYC(20),VELZC(20),VELXE(20),
     8.000                       $VELYE(20),VELZE(20),B2(20),B2X(20),B2Y(20),B2Z(20),
     9.000                       $B1X(20),B1Y(20),B1Z(20),CX(20),CY(20),CZ(20),R1X(20),
    10.000                       $R1Y(20),R1Z(20),R2X(20),R2Y(20),R2Z(20),B3X(20),B3Y(20),
    11.000                       $B3Z(20),TIME(20),WK(3000),WB1(20),WB2(20),WB3(20),
    12.000                       $Y1(20),Y2(20),Y3(20),Y4(20),Y5(20),Y6(20),Y7(20),
    13.000                       $Y8(20),DS(20),Y9(20),
    14.000                       $ DEN1(20),DEN2(20),DEN3(20),DEN4(20),DENOM(20),
    15.000                       $ WN1(20),DEN5(20),WN2(20),WN3(20),W(20)
    16.000       0003             COMMON N,A(10,11),NP1
    17.000       0004             N=3
    18.000       0005             NP1=N+1
    19.000       0006             READ(5,1)NFRAME,TIN,DSS
    20.000       0007       1     FORMAT(I2,2F5.3)
    21.000       0008             M=NFRAME-1
    22.000       0009             IOU=6
    23.000       0010             DO 12 I=1,NFRAME
    24.000       0011       12    DS(I)=DSS
    25.000       0012             IC=NFRAME-1
    26.000       0013             XI=NFRAME
    27.000       0014             SM=NFRAME
    28.000       0015             TIME(1)=0.0
    29.000       0016             DO 11 I=2,NFRAME
    30.000       0017       11    TIME(I)=TIME(I-1)+.01
    31.000       0018             WRITE(6,66) (TIME(I),I=1,NFRAME)
    32.000       0019       66    FORMAT(10F5.4)
    33.000       0020             DO 10 I=1,NFRAME
    34.000                  C     READ IN COORDINATES OF SEGMENTAL ENDPOINTS
    35.000       0021             READ(5,2)XA(I),YA(I),ZA(I)
    36.000       0022             READ(5,2)XB(I),YB(I),ZB(I)
    37.000       0023             READ(5,2)XC(I),YC(I),ZC(I)
    38.000       0024             READ(5,2)XD(I),YD(I),ZD(I)
    39.000       0025             READ(5,2)XE(I),YE(I),ZE(I)
    40.000       0026       10    CONTINUE
    40.200       0027             Z=.0254
    41.000       0028             DO 44 I=1,NFRAME
    42.000       0029             XA(I)=XA(I)*.0254
    43.000       0030             YA(I)=YA(I)*.0254
    44.000       0031             ZA(I)=ZA(I)*Z
    45.000       0032             XB(I)=XB(I)*Z
    46.000       0033             YB(I)=YB(I)*Z
    47.000       0034             ZB(I)=ZB(I)*Z
    48.000       0035             XC(I)=XC(I)*Z
    49.000       0036             YC(I)=YC(I)*Z
    50.000       0037             ZC(I)=ZC(I)*Z
    51.000       0038             XD(I)=XD(I)*Z
    52.000       0039             YD(I)=YD(I)*Z
    53.000       0040             ZD(I)=ZD(I)*Z
    54.000       0041             XE(I)=XE(I)*Z
```

```
             YE(I)=YE(I)*Z
             ZE(I)=ZE(I)*Z
      44     CONTINUE
      2      FORMAT(10X,3(E12.5,2X))
             CALL ICSSCU(TIME,XB,DS,NX,SM,Y1,XC1,IC,WK,IER)
             CALL ICSSCU(TIME,YB,DS,NX,SM,Y2,YC1,IC,WK,IER)
             CALL ICSSCU(TIME,ZB,DS,NX,SM,Y3,ZC1,IC,WK,IER)
             CALL ICSSCU(TIME,XC,DS,NX,SM,Y4,XC2,IC,WK,IER)
             CALL ICSSCU(TIME,YC,DS,NX,SM,Y5,YC2,IC,WK,IER)
             CALL ICSSCU(TIME,ZC,DS,NX,SM,Y6,ZC2,IC,WK,IER)
             CALL ICSSCU(TIME,XE,DS,NX,SM,Y7,XC3,IC,WK,IER)
             CALL ICSSCU(TIME,YE,DS,NX,SM,Y8,YC3,IC,WK,IER)
             CALL ICSSCU(TIME,ZE,DS,NX,SM,Y9,ZC3,IC,WK,IER)
      C  CALCULATE THE RELATIVE LINEAR VELOCITIES OF POINTS C AND
      C E WITH RESPECT TO B
             N=NX-1
             DO 13 I=1,N
             VELXB(I)=XC1(I,1)
             VELYB(I)=YC1(I,1)
             VELZB(I)=ZC1(I,1)
             VELXC(I)=XC2(I,1)-VELXB(I)
             VELYC(I)=YC2(I,1)-VELYB(I)
             VELZC(I)=ZC2(I,1)-VELZB(I)
             VELXE(I)=XC3(I,1)-VELXB(I)
             VELYE(I)=YC3(I,1)-VELYB(I)
             VELZE(I)=ZC3(I,1)-VELZB(I)
      13     CONTINUE
             DO 8 I=1,N
      8       WRITE(6,27)TIME(I),XB(I),TIME(I),Y1(I),VELXB(I)
             DO 9 I=1,N
      9      WRITE(6,27)TIME(I),YB(I),TIME(I),Y2(I),VELYB(I)
             DO 100 I=1,N
      100     WRITE(6,27)TIME(I),ZB(I),TIME(I),Y3(I),VELZB(I)
      27     FORMAT(F5.3,F10.5,F5.3,2F15.5)
      C  CALCULATE THE TOTAL ANGULAR VELOCITY W
      C MUST FIRST DEFINE THE VECTORS LYING IN THE ARM SEGMENT
             DEN1(I)=SQRT((XC(I)-XB(I))**2+(YC(I)-YB(I))**2+(ZC(I)-ZB(I))**2)
             DO 50 I=1,N
             DEN2(I)=SQRT((XE(I)-XB(I))**2+(YE(I)-YB(I))**2+(ZE(I)-ZB(I))**2)
             R1X(I)=(XC(I)-XB(I))/DEN1(I)
            R1Y(I)=(YC(I)-YB(I))/DEN1(I)
             R1Z(I)=(ZC(I)-ZB(I))/DEN1(I)
             R2X(I)=(XE(I)-XB(I))/DEN2(I)
             R2Y(I)=(YE(I)-YB(I))/DEN2(I)
             R2Z(I)=(ZE(I)-YB(I))/DEN2(I)
             DENOM(I)=(VELXC(I)*R2X(I))+(VELYC(I)*R2Y(I))
           $ +(VELZC(I)*R2Z(I))
             WN1(I)=(VELYC(I)*VELZE(I)-VELZC(I)*VELYE(I))/DENOM(I)
             WN2(I)=(VELZC(I)*VELXE(I)-VELXC(I)*VELZE(I))/DENOM(I)
             WN3(I)=(VELXC(I)*VELYE(I)-VELYC(I)*VELXE(I))/DENOM(I)
      C  FIND THE VECTORS WHICH DEFINE THE ARM SEGMENTS:B1,B2,B3
      C  B2=B2X+B2Y+B2Z
              DEN3(I)=SQRT((XC(I)-XB(I))**2+(YC(I)-YB(I))**2+(ZC(I)-ZB(I))**2)
             B2X(I)=(XC(I)-XB(I))/DEN3(I)
             B2Y(I)=(YC(I)-YB(I))/DEN3(I)
```

```
MTS  FORTRAN IV G COMPILER (O/S REL 21.8)          MAIN      06-29-78    08:56:23         PAGE 0003

                    B2Z(I)=(ZC(I)-ZB(I))/DEN3(I)
                    DEN4(I)=SQRT((XB(I)-XA(I))**2+(YB(I)-YA(I))**2+(ZB(I)
                  $ -ZA(I))**2)
                    CX(I)=(XB(I)-XA(I))/DEN4(I)
                    CY(I)=(YB(I)-YA(I))/DEN4(I)
                    CZ(I)=(ZB(I)-ZA(I))/DEN4(I)
              C FORM C X B TO FIND B1 VECTOR
                    B1X(I)=(CY(I)*B2Z(I))-(CZ(I)*B2Y(I))
                    B1Y(I)=(CZ(I)*B2X(I))-(CX(I)*B2Z(I))
                    B1Z(I)=(CX(I)*B2Y(I))-(CY(I)*B2X(I))
                    DEN5(I)=SQRT(B1X(I)**2+B1Y(I)**2+B1Z(I)**2)
                    B1X(I)=B1X(I)/DEN5(I)
                    B1Y(I)=B1Y(I)/DEN5(I)
                    B1Z(I)=B1Z(I)/DEN5(I)
              C  FORM B1 X B2 TO FORM B3 VECTOR
                    B3X(I)=(B1Y(I)*B2Z(I))-(B1Z(I)*B2Y(I))
                    B3Y(I)=(B1Z(I)*B2X(I))-(B1X(I)*B2Z(I))
                    B3Z(I)=(B1X(I)*B2Y(I))-(B1Y(I)*B2X(I))
              C MUST FORM THE DOT PRODUCT OF OMEGA WITH EACH OF THE
              C UNIT VECTORS TO FROM 3 EQUATIONS IN THREE UNKNOWNS
              C WHICH MAY BE SOLVED FOR THE COMPONENTS OF OMEGA
                    WB1(I)=(WN1(I)*B1X(I)+WN2(I)*B1Y(I)+WN3(I)*B1Z(I))
                    WB2(I)=(WN1(I)*B2X(I)+WN2(I)*B2Y(I)+WN3(I)*B2Z(I))
                    WB3(I)=(WN1(I)*B3X(I)+WN2(I)*B3Y(I)+WN3(I)*B3Z(I))
              C MUST SOLVE THIS SYSTEM OF EQUATIONS FOR THE UNKNOWN QUANTITIES
              C USE SUBROUTINE SOLVE TO SOLVE THESE
                    A(1,1)=B1X(I)
                    A(1,2)=B1Y(I)
                    A(1,3)=B1Z(I)
                    A(1,4)=WB1(I)
                    A(2,1)=B2X(I)
                    A(2,2)=B2Y(I)
                    A(2,3)=B2Z(I)
                    A(2,4)=WB2(I)
                    A(3,1)=B3X(I)
                    A(3,2)=B3Y(I)
                    A(3,3)=B3Z(I)
                    A(3,4)=WB3(I)
                    CALL SOLVE
                    WRITE(6,60)
              60    FORMAT('-','SOLUTION OF THE SYSTEM OF EQUATIONS')
                    WRITE(6,62)I,(K,A(K,NP1),K=1,N)
              62    FORMAT('PHASE NUMBER',I5,'W',I3,F10.5,'W',
                  $ I3,F10.5,'W',I3,F10.5)
              50   CONTINUE
                    STOP
                    END
```

```
MTS  FORTRAN IV G COMPILER (O/S REL 21.8)          SOLVE      06-29-78    08:56:25          PAGE 0001

                 SUBROUTINE SOLVE
                 COMMON N,A(10,11),NP1
                 K=1
                 DO 70 IROW=1,N
                 K=K+1
                 ISWAP=IROW
                 DO 50 IN=K,N
                 IF(ABS(A(ISWAP,IROW))-ABS(A(IN,IROW)).GE.0.)GO TO 50
                 ISWAP=IN
          50     CONTINUE
                 IF(ISWAP.EQ.IROW) GO TO 99
                 DO 92 J=1,NP1
                 TEMP=A(IROW,J)
                 A(IROW,J)=A(ISWAP,J)
          92     A(ISWAP,J)=TEMP
          99     PIVOT=A(IROW,IROW)
                 IF (ABS(PIVOT)-1.E-06)27,27,28
          27     WRITE(6,65)PIVOT
          65     FORMAT('-','PIVOT IS TOO SMALL. VALUE OF PIVOT
               $ =',F10.5)
                 STOP
          28     DO 10 J=1,NP1
          10     A(IROW,J)=A(IROW,J)/PIVOT
                  DO 20 I=1,N
                 IF(I.EQ.IROW)GO TO 20
                 RATIO=A(I,IROW)
                 DO 18 J=1,NP1
          18     A(I,J)=A(I,J)-A(IROW,J)*RATIO
          20     CONTINUE
          70     CONTINUE
                 RETURN
                 END
```

APPENDIX G

Raw Data for Planar Analysis

```
                    SEGMENTAL ANALYSIS PROGRAM-3 SEGMENTS
                     ANGULAR KINEMATICS OF THE UPPER ARM

           INPUT                                          OUTPUT

    X           F          TIME       DISPLACEMENT      VELOCITY      ACCELERATION
 0.0         -1.143      0.0           -1.1731           7.6048          0.0
 0.020       -1.005      0.020         -1.0191           7.7690         10.4172
 0.040       -0.859      0.040         -0.8606           8.1290         25.5791
 0.060       -0.694      0.060         -0.6919           8.7964         41.1555
 0.080       -0.520      0.080         -0.5067           9.7631         56.0170
 0.100       -0.296      0.100         -0.2995          10.9922         66.3844
 0.120       -0.080      0.120         -0.0656          12.4355         77.9421
 0.140        0.164      0.140          0.1992          14.0586         84.3684
 0.160        0.461      0.160          0.4968          15.6900         76.7656
 0.180        0.772      0.180          0.8252          17.0850         60.7350
 0.200        1.221      0.200          1.1766          17.9351         24.2721
 0.220        1.605      0.220          1.5387          18.2084          3.0583
 0.240        1.921      0.240          1.9036          18.2658          4.6334
 0.260        2.254      0.260          2.2708          18.4565         12.3660
 0.280        2.611      0.280          2.6425          18.7237         14.3238
 0.300        2.947      0.300          3.0193          18.9212          5.4201
 0.320        3.384      0.320          3.3965          18.6919        -28.3466
 0.340        3.778      0.340          3.7612          17.6065        -60.2009
 0.360        4.199      0.360          4.0943          15.5402       -126.4216
 0.380        4.525      0.380          4.3791          12.9097       -136.6317
 0.400        4.627      0.400          4.6126          10.5763        -96.6961
 0.420        4.766      0.420          4.8078           9.0897        -51.9702
 0.440        4.960      0.440          4.9612           8.3523        -21.6566
 0.460        5.075      0.460          5.1455           6.1493          1.3643

N.B.  DATA FOR SUBJECT 1, PITCH 1, TIME INTERVAL .02 SECONDS BETWEEN FRAMES
```

```
                    SPECTRAL ANALYSIS PROGRAM-S SIGMA 15

                    ANGULAR KINEMATICS OF THE LOWER ARM

        INPUT                                        OUTPUT

   X           F          TIME        DISPLACEMENT        VELOCITY        ACCELERATION
 0.0        -1.0[illegible]      0.0           -1.0[illegible]75          8.4[illegible]            0.0
 0.020      -0.916      0.020         -0.9162           8.[illegible]36            2.3763
 0.040      -0.7[illegible]      0.040         -0.7474           8.6275           11.9955
 0.060      -0.56[illegible]     0.060         -0.5746           8.5[illegible]56          -19.7549
 0.080      -0.407      0.080         -0.4063           8.3[illegible]96           -1.72[illegible]8
 0.100      -0.2[illegible]      0.100         -0.2390           8.4736           15.[illegible]57[illegible]
 0.120      -0.070      0.120         -0.0562           8.7[illegible]96           1[illegible].[illegible]264
 0.140       0.12[illegible]     0.140          0.1125           9.0539           [illegible].[illegible]611
 0.160       0.2[illegible]      0.160          0.2957           9.3705           25.[illegible]91[illegible]
 0.180       0.5[illegible]3     0.180          0.4[illegible]4            9.9[illegible]30           2[illegible].1[illegible]32
 0.200       0.6[illegible]4     0.200          0.6[illegible]42           10.7769          [illegible].[illegible]049
 0.220       0.91[illegible]     0.220          0.9225          12.2435           87.[illegible]381
 0.240       1.1[illegible]      0.240          1.1564          14.0799           94.[illegible]725
 0.260       1.477      0.260          1.4[illegible]64          15.9199           89.[illegible]204
 0.280       1.[illegible]       0.280          1.[illegible]23[illegible]         17.4[illegible]1           [illegible]4.[illegible]7[illegible]7
 0.300       2.20[illegible]     0.300          2.1[illegible]59          19.[illegible]4[illegible]0          11[illegible].[illegible]350
 0.320       2.6[illegible]      0.320          2.5[illegible]91          22.3[illegible]03          15[illegible].7977
 0.340       3.0[illegible]1     0.340          3.0[illegible]11          27.1[illegible]02          2[illegible]7.1[illegible]5
 0.360       3.[illegible]       0.360          3.5[illegible]2          32.[illegible]53          2[illegible]5.29[illegible]5
 0.380       4.3[illegible]      0.380          4.3789          35.27[illegible]5          -[illegible]5.9547
 0.400       5.1[illegible]      0.400          5.0[illegible]18          31.[illegible]5[illegible]         -33[illegible].3[illegible]5[illegible]
 0.420       5.7[illegible]      0.420          5.5[illegible]20          23.[illegible]46         -470.[illegible]551
 0.440       6.1[illegible]      0.440          6.0153          15.5[illegible]50         -[illegible]53.0417
 0.460       6.2[illegible]      0.460          6.2075          1[illegible].[illegible]712         -159.4[illegible]19

N.B.  DATA FOR SUBJECT 1, TRIAL [illegible], TIME INTERVAL .02 SECONDS BETWEEN FRAMES
```

```
                    SEGMENTAL ANALYSIS PROGRAM-3 SEGMENTS

                    ANGULAR KINEMATICS OF THE HAND SEGMENT

       INPUT                                               OUTPUT

   X           F          TIME        DISPLACEMENT      VELOCITY       ACCELERATION
0.0         -2.154       0.0            -2.1914          7.4653           0.0
0.020       -2.058       0.020          -2.0388          7.9546          48.9229
0.040       -1.936       0.040          -1.8683          9.1714          72.7579
0.060       -1.660       0.060          -1.6749          9.5420           4.3022
0.080       -1.419       0.080          -1.4784          9.5437         -44.1364
0.100       -1.244       0.100          -1.2944          8.9600         -14.2321
0.120       -1.122       0.120          -1.1116          9.6481          83.0406
0.140       -0.945       0.140          -0.8964         12.1425         165.4044
0.160       -0.689       0.160          -0.6190         15.6675         186.0903
0.180       -0.359       0.180          -0.2733         18.6548         112.6382
0.200        0.284       0.200           0.1099         19.0413         -73.9818
0.220        0.451       0.220           0.4788         17.9994         -30.2065
0.240        0.832       0.240           0.8332         17.4707         -22.6609
0.260        1.211       0.260           1.1786         17.0619         -16.2174
0.290        1.536       0.280           1.5203         17.2524          33.3022
0.300        1.951       0.300           1.8767         18.6263         104.1042
0.320        2.243       0.320           2.2814         22.4049         273.6929
0.340        2.715       0.340           2.7921         29.0631         392.1384
0.360        3.265       0.360           3.4529         37.0697         401.5199
0.380        3.962       0.380           4.2605         42.9143         175.9435
0.400        5.398       0.400           5.1121         40.1531        -452.0520
0.420        6.127       0.420           5.8081         28.6211        -701.1567
0.440        6.348       0.440           6.2518         16.3257        -528.3523
0.460        6.438       0.460           6.4927          8.7634        -227.6471

N.B.  DATA FOR SUBJECT 1, PITCH 1, TIME INTERVAL .02 SECONDS BETWEEN FRAMES
```

```
                    LINEAR KINEMATICS OF SHOULDER


       INPUT                                          OUTPUT

   X          Y          TIME       DISPLACEMENT       VELOCITY       ACCELERATION

                         Y-COORDINATES OF SHOULDER
 0.0        0.282       0.0          0.2155            1.0316           0.0
 0.020      0.302       0.020        0.2060            1.0204          -1.5530
 0.040      [illegible] 0.040        0.3261            0.9778          -3.1402
 0.060      0.350       0.060        0.2442            0.8861          -5.7769
 0.080      0.367       0.080        0.3014            0.7656          -7.0291
 0.100      0.377       0.100        0.3752            0.6227          -6.7431
 0.120      0.404       0.120        0.3563            0.4972          -5.6100
 0.140      0.398       0.140        0.3955            0.4[illegible]  -0.2871
 0.160      0.457       0.160        0.4344            0.4643           3.1263
 0.180      0.416       0.180        0.4146            0.5674           7.1847
 0.200      0.477       0.200        0.4275            0.7651          11.5981
 0.220      0.4[illegible] 0.220     0.4452            1.0301          15.5664
 0.240      0.45[illegible] 0.240    0.4692            1.3652          17.3012
 0.260      [illegible] 0.260        0.4958            1.5851          15.1112
 0.280      0.534       0.280        0.5365            1.8445          10.4803
 0.300      [illegible] 0.300        0.5768            2.0867           4.9506
 0.320      [illegible] 0.320        0.6188            2.1809           3.6409
 0.340      [illegible] 0.340        0.6649            2.2152          -0.5162
 0.360      0.717       0.360        0.7062            2.2[illegible]   0.0782
 0.380      0.74[illegible] 0.380    0.7526            2.2426           3.1354
 0.400      0.75[illegible] 0.400    0.79[illegible]1  2.3152           4.1354
 0.420      [illegible] 0.420        0.8452            2.3[illegible]   2.6867
 0.440      [illegible] 0.440        0.7935            2.4214           0.6583
 0.460      0.9[illegible]7 0.460    0.9437            2.3567          -3.1250

N.B.  DATA FOR SUBJECT 1, TRIAL 1, TIME INTERVAL .02 SECONDS [illegible] 24 FRAMES
```

```
                        LINEAR KINEMATICS OF SHOULDER


         INPUT                                              OUTPUT

   X            F            TIME        DISPLACEMENT      VELOCITY       ACCELERATION

                             Y-COORDINATES OF SHOULDER
 0.0          0.630        0.0             0.6106           -1.4273           0.0
 0.020        0.562        0.020           0.5853           -0.9492          47.8026
 0.040        0.574        0.040           0.5751           -0.1067          36.4503
 0.060        0.576        0.060           0.5793            0.4811          22.3311
 0.080        0.601        0.080           0.5919            0.7005          -0.3616
 0.100        0.603        0.100           0.6059            0.7026           0.5366
 0.120        0.617        0.120           0.6196            0.6847          -6.3217
 0.140        0.630        0.140           0.6304            0.3866         -19.4719
 0.160        0.639        0.160           0.6333           -0.1430         -33.4913
 0.180        0.625        0.180           0.6238           -0.8039         -32.5965
 0.200        0.614        0.200           0.6020           -1.3354         -20.5528
 0.220        0.548        0.220           0.5739           -1.3265          21.4375
 0.240        0.560        0.240           0.5501           -1.1411          -2.8563
 0.260        0.524        0.260           0.5267           -1.1910          -2.0884
 0.280        0.510        0.280           0.5020           -1.3006          -3.3774
 0.300        0.473        0.300           0.4756           -1.3589           3.5480
 0.320        0.446        0.320           0.4489           -1.2275          10.0925
 0.340        0.435        0.340           0.4264           -1.0241          10.2476
 0.360        0.402        0.360           0.4095           -0.6060          32.1620
 0.380        0.405        0.380           0.4041            0.0729          35.1303
 0.400        0.407        0.400           0.4129            0.8307          40.6504
 0.420        0.430        0.420           0.4370            1.5400          30.2790
 0.440        0.484        0.440           0.4721            1.8766           3.3819
 0.460        0.506        0.460           0.5105            1.9300           6.9567

N.B.  DATA FOR SUBJECT 1, PITCH 1, TIME INTERVAL .02 SECONDS BETWEEN FRAMES
```

LINEAR VELOCITIES AND ACCELERATIONS OF SEGMENTAL ENDPOINTS

KINEMATICS OF THE ARM CENTER OF GRAVITY

FRAME	X-VELOCITY	Y-VELOCITY	X-ACCELERATION	Y-ACCELERATION
1	2.2018	-0.9354	2.2927	26.4849
2	2.1165	-0.2746	-4.2455	76.1869
3	1.9990	0.7714	-15.4812	66.2014
4	1.8179	1.6034	-28.3608	54.1523
5	1.5455	2.1158	-41.0719	32.7738
6	1.1600	2.4427	-55.0526	31.4379
7	0.6322	2.7005	-71.6579	16.5871
8	-0.0250	2.6696	-82.1083	-14.5020
9	-0.7747	2.1422	-83.0765	-59.3221
10	-1.5122	1.1165	-61.7398	-97.5659
11	-1.9885	-0.1941	-15.1112	-118.3251
12	-1.9351	-1.2298	35.5156	-65.7114
13	-1.5001	-2.1309	79.0473	-93.3103
14	-0.6497	-3.1609	118.9822	-71.2406
15	0.4602	-4.0244	150.5871	-38.3661
16	1.7162	-4.4704	165.6122	25.2681
17	2.9659	-4.2243	153.8768	88.9601
18	3.9093	-3.3988	105.5929	128.4765
19	4.3081	-2.0921	45.5145	153.4245
20	4.2531	-0.6268	1.5221	131.3251
21	4.0587	0.6562	-16.3078	109.0270
22	3.8856	1.6835	-22.6714	62.3995
23	3.7557	2.2442	-25.5193	48.2187
24	3.6223	2.5467	-29.6559	49.4896

N.B. DATA FOR SUBJECT 1, PITCH 1, TIME INTERVAL .02 SECONDS BETWEEN FRAMES

LINEAR VELOCITIES AND ACCELERATIONS OF SEGMENTAL ENDPOINTS

WRIST KINEMATICS

FRAME	X-VELOCITY	Y-VELOCITY	X-ACCELERATION	Y-ACCELERATION
1	5.7687	0.8409	-4.8208	78.3022
2	5.4892	2.0922	-19.5459	124.3236
3	5.0206	3.7423	-41.2462	115.6415
4	4.3681	5.1364	-69.7028	93.4787
5	3.5168	6.1665	-86.8400	72.1184
6	2.4363	7.0814	-109.7870	70.0888
7	0.9754	7.9034	-139.7255	46.4380
8	-0.9146	8.2263	-160.2663	-2.6181
9	-3.1695	7.6979	-165.4043	-67.1394
10	-5.5504	6.1376	-135.9407	-136.5026
11	-7.5371	3.6841	-70.5350	-184.4372
12	-8.7179	1.0365	1.8497	-177.0702
13	-8.9868	-1.8811	79.0626	-214.7741
14	-8.2726	-5.3202	175.6719	-202.3913
15	-6.3624	-8.7994	294.4849	-156.6344
16	-3.3357	-11.7156	363.6572	-59.3230
17	0.6316	-13.6495	428.1150	60.5683
18	5.7028	-14.3371	460.8013	214.1611
19	11.9658	-12.1097	459.3623	494.5918
20	16.5448	-4.6608	144.4057	725.1421
21	15.0607	3.5915	-242.5308	556.0769
22	10.0823	7.3272	-291.9929	213.3939
23	6.6875	7.0787	-167.6882	52.6055
24	5.2553	6.3160	-96.2629	58.4159

N.B. DATA FOR SUBJECT 1, PITCH 1, TIME INTERVAL .02 SECONDS BETWEEN FRAMES

LINEAR VELOCITIES AND ACCELERATIONS OF SEGMENTAL ENDPOINTS

ELBOW KINEMATICS

FRAME	X-VELOCITY	Y-VELOCITY	X-ACCELERATION	Y-ACCELERATION
1	3.7163	-0.2991	2.2927	28.4849
2	3.5345	0.5982	-2.3441	77.3371
3	3.3200	1.9073	-11.3244	69.7756
4	3.0206	3.0551	-22.6736	65.9445
5	2.5615	3.9463	-35.2454	43.2708
6	1.8550	4.6937	-50.8554	45.0323
7	0.8068	5.3660	-70.5033	33.2557
8	-0.6211	5.6233	-85.6857	3.2224
9	-2.3775	5.0983	-91.1227	-44.4820
10	-4.2023	3.6006	-71.3925	-88.7350
11	-5.5376	1.2822	-19.9142	-116.3272
12	-5.8855	-1.1048	38.8605	-85.6904
13	-5.2041	-3.4114	78.0986	-98.6382
14	-3.6751	-5.7091	116.9519	-72.9567
15	-1.4664	-7.5478	149.1168	-41.0054
16	1.2215	-8.4953	165.4705	24.1151
17	3.9762	-8.1009	152.3447	94.8390
18	6.1967	-6.4767	95.6105	142.4694
19	7.0224	-4.0222	23.4333	169.1313
20	6.8777	-1.5320	-26.1494	140.9053
21	6.3142	0.4304	-36.9266	111.0911
22	5.8243	1.6690	-33.7590	81.3385
23	5.4816	2.7197	-29.9941	46.9560
24	5.2077	3.2797	-29.4022	49.6359

N.B. DATA FOR SUBJECT 1, PITCH 1, TIME INTERVAL .02 SECONDS BETWEEN FRAMES

LINEAR VELOCITIES AND ACCELERATIONS OF SEGMENTAL ENDPOINTS

KINEMATICS OF THE LOWER ARM CENTER OF GRAVITY

FRAME	X-VELOCITY	Y-VELOCITY	X-ACCELERATION	Y-ACCELERATION
1	4.6504	0.1911	-4.8208	78.3022
2	4.3750	1.2406	-19.6579	124.0551
3	4.0513	2.6964	-42.5940	114.1871
4	3.6000	3.9501	-67.9272	96.2212
5	2.9722	4.9010	-86.7264	72.3824
6	2.1049	5.7204	-110.3993	67.5740
7	0.6793	6.4536	-139.8996	43.6111
8	-0.7473	6.7426	-160.1107	-3.9980
9	-2.7181	6.2161	-164.1810	-71.1543
10	-4.7820	4.6915	-133.7547	-140.6166
11	-6.3974	2.3150	-64.3135	-191.9141
12	-7.1034	-0.1840	13.4321	-185.8262
13	-6.8307	-2.7534	93.6006	-220.0651
14	-5.6520	-5.5419	190.5346	-203.6313
15	-3.5683	-8.0860	294.8276	-153.9438
16	-0.7381	-9.8800	379.1665	-48.3493
17	2.5380	-10.4868	444.7380	48.1456
18	5.9296	-9.8532	483.1992	261.5923
19	9.1481	-7.4998	436.4917	532.0383
20	11.0345	-2.9720	145.3358	724.8198
21	10.0494	1.7897	-190.5900	574.9735
22	7.6466	4.2166	-244.3199	278.7917
23	6.0002	4.5941	-152.1286	103.3509
24	5.2282	4.5853	-95.8500	34.7618

N.B. DATA FOR SUBJECT 1, PITCH 1, TIME INTERVAL .02 SECONDS BETWEEN FRAMES

2

LINEAR VELOCITIES AND ACCELERATIONS OF SEGMENTAL ENDPOINTS

KINEMATICS OF THE HAND CENTER OF GRAVITY

FRAME	X-VELOCITY	Y-VELOCITY	X-ACCELERATION	Y-ACCELERATION
1	6.1501	0.6540	-6.1170	46.1091
2	5.7947	1.9378	-29.9221	31.6483
3	5.3980	3.6266	-68.7949	16.2426
4	4.7536	5.0919	-119.0057	-11.1844
5	3.9257	6.2044	-148.8735	-39.5127
6	2.6073	7.1866	-177.1921	-76.2542
7	1.3476	8.0874	-219.1161	-115.9055
8	-0.5064	8.5526	-266.7104	-149.1991
9	-2.7783	8.2471	-312.0923	-186.6493
10	-5.3337	6.9107	-300.6299	-220.3754
11	-7.6270	4.4987	-195.7397	-223.3268
12	-9.0748	1.7240	-60.4039	-179.1632
13	-9.5433	-1.3755	81.1010	-113.3212
14	-8.9519	-5.0392	250.2525	-7.1496
15	-7.1040	-8.7619	432.5569	129.0952
16	-4.1001	-11.9570	593.6689	249.3221
17	-0.0992	-14.2784	775.3259	376.1016
18	5.2745	-15.5122	1013.6772	580.2314
19	12.4545	-13.6284	1114.7079	450.8648
20	18.2062	-5.6673	484.2544	1105.7490
21	16.5925	4.2639	-501.0389	580.4973
22	10.6257	8.4225	-627.4700	26.7563
23	6.7095	7.7810	-324.9111	-79.9542
24	5.1769	6.6849	-161.1138	-62.2545

N.B. DATA FOR SUBJECT 1, PITCH 1, TIME INTERVAL .02 SECONDS BETWEEN FRAMES

LINEAR VELOCITIES AND ACCELERATIONS OF SEGMENTAL ENDPOINTS

FINGERTIP KINEMATICS

FRAME	X-VELOCITY	Y-VELOCITY	X-ACCELERATION	Y-ACCELERATION
1	6.8222	0.1736	-6.1170	46.1091
2	6.5803	1.5407	-25.0903	29.4060
3	6.3683	3.3291	-61.0870	13.9820
4	5.8679	4.9776	-118.5322	-11.2339
5	4.9774	6.3018	-153.7370	-39.9631
6	3.7612	7.4572	-178.7073	-76.6840
7	2.3047	8.5607	-210.8786	-111.8322
8	0.5432	9.3916	-254.3264	-137.7010
9	-1.7723	9.6592	-300.1436	-169.8708
10	-4.7764	8.8984	-297.2651	-206.3732
11	-7.8580	6.5931	-194.8332	-231.4066
12	-9.9925	3.4919	-58.8638	-182.1301
13	-10.9742	-0.0754	82.9570	-115.0076
14	-10.6987	-4.3166	251.9169	-7.8356
15	-9.0108	-8.6654	426.8762	129.2613
16	-6.0058	-12.5776	582.6331	245.9527
17	-1.9786	-15.8956	752.3679	356.3459
18	4.1732	-18.5540	998.6178	545.4595
19	13.7109	-17.5335	1128.5542	997.8491
20	22.4765	-7.7612	501.8005	1097.2461
21	20.6355	5.9930	-547.1719	561.0208
22	12.0744	11.2391	-662.9604	-42.2441
23	6.7662	9.5667	-326.7441	-138.3984
24	4.9752	7.6335	-155.8744	-86.9175

N.B. DATA FOR SUBJECT 1, PITCH 1, TIME INTERVAL .02 SECONDS BETWEEN FRAMES

```
                  KINETICS OF THE UPPER EXTREMITY

              FORCES AND MOMENTS AT THE WRIST JOINT

FRAME   X-JOINT FORCES    Y-JOINT FORCES      MOMENT AT THE JOINT
  1            -5.37070          49.10043                -1.04072
  2           -26.27161          34.43518                 0.50295
  3           -66.39313          20.80513                 2.46393
  4.         -104.48700          -1.24669                 4.49221
  5          -130.71094         -26.47092                 5.34372
  6          -155.57466         -58.71182                 5.70446
  7          -192.58394         -89.57193                 5.95869
  8          -235.92776        -112.28474                 5.46616
  9          -274.01685        -140.53510                 2.53423
 10          -263.95268        -174.33496                -3.78382
 11          -171.65159        -194.61096                -9.38121
 12           -53.03459        -151.29349                -6.93070
 13            71.20667         -92.36000                -0.48013
 14           219.72173           1.73705                 8.71256
 15           379.78491         122.12570                16.69958
 16           521.29121         224.47533                18.52706
 17           660.73608         321.48804                14.09057
 18           890.00854         497.52979                -5.29510
 19           978.71338         805.70776               -44.55217
 20           425.20166         971.99854               -34.14516
 21          -439.95581         501.20142                24.33417
 22          -550.51846         -28.47360                 7.42699
 23          -285.27197        -112.89708                -6.22559
 24          -141.46227         -67.69690                -4.87237

N.B.  DATA FOR SUBJECT 1, PITCH 1, TIME INTERVAL .02 SECONDS BETWEEN FRAMES
```

KINETICS OF THE UPPER EXTREMITY

FORCES AND MOMENTS AT THE ELBOW JOINT

FRAME	X-JOINT FORCES	Y-JOINT FORCES	MOMENT AT THE JOINT
1	-15.10867	227.09518	-6.27797
2	-66.38461	304.91138	0.52797
3	-146.43295	271.28735	10.12582
4	-241.70006	212.94446	20.96321
5	-305.89819	139.56537	27.35689
6	-378.58130	97.61191	33.15852
7	-474.98096	18.75078	35.64050
8	-559.35132	-100.53647	30.28587
9	-605.66266	-264.44238	18.74574
10	-534.13721	-438.55591	5.37189
11	-301.76489	-562.45313	3.00203
12	-25.90181	-506.82789	6.59447
13	260.27979	-518.25905	30.14914
14	604.60156	-389.77466	73.51569
15	975.33667	-169.11740	133.15681
16	1287.15800	146.63409	181.59136
17	1579.10693	519.36670	198.81239
18	1366.07104	1035.77148	153.31067
19	1860.42576	1960.16896	10.31633
20	718.77979	2455.95898	-58.48455
21	-824.94751	1682.48242	69.44273
22	-1044.44458	546.42993	104.75453
23	-592.57202	126.80606	42.02040
24	-335.07910	123.34613	12.97731

N.B. DATA FOR SUBJECT 1, PITCH 1, TIME INTERVAL .02 SECONDS BETWEEN FRAMES

KINETICS OF THE UPPER EXTREMITY

FORCES AND MOMENTS AT THE SHOULDER JOINT

FRAME	X-JOINT FORCES	Y-JOINT FORCES	MOMENT AT THE JOINT
1	-7.03840	327.36182	37.64148
2	-81.32861	573.01855	108.63632
3	-200.92673	504.31616	152.78003
4	-341.31885	403.56030	178.70354
5	-450.47095	254.92967	161.17708
6	-572.36646	208.27347	141.22972
7	-727.21655	77.13725	70.92479
8	-848.37256	-151.58351	-62.91206
9	-898.04160	-473.25635	-229.00272
10	-751.46118	-781.93779	-318.93335
11	-354.95630	-978.95752	-216.43259
12	95.11320	-608.54199	11.83637
13	538.52612	-864.31104	250.49854
14	1023.41970	-640.54126	425.08936
15	1505.40332	-303.95483	429.30469
16	1670.15208	235.57780	183.36722
17	2120.75317	832.50625	-217.63755
18	2237.75761	1468.00854	-679.54590
19	2020.63745	2440.26074	-1063.36182
20	724.13745	2916.22339	-654.39771
21	-882.35059	2066.25732	336.15283
22	-1124.24605	836.47607	534.86208
23	-682.39990	296.53589	292.66140
24	-439.46777	297.59932	176.05616

N.B. DATA FOR SUBJECT 1, PITCH 1, TIME INTERVAL .02 SECONDS BETWEEN FRAMES

```
                         SEGMENTAL ANALYSIS PROGRAM-3 SEGMENTS
                          ANGULAR KINEMATICS OF THE UPPER ARM

                                                                   OUTPUT
           INPUT

   X              θ              TIME            DISPLACEMENT        VELOCITY         ACCELERATION
                                                                                          0.0
 0.0            1.127           0.0                1.1393            19.3107          -16.5239
 0.010          1.343           0.010              1.3321            19.2281          -18.5707
 0.020          1.513           0.020              1.5236            19.0527          -35.8254
 0.030          1.725           0.030              1.7129            18.7806          -36.7579
 0.040          1.893           0.040              1.8989            18.4177          -46.9031
 0.050          2.108           0.050              2.0811            18.0019          -18.1510
 0.060          2.252           0.060              2.2592            17.6791            6.0109
 0.070          2.442           0.070              2.4354            17.5854           27.9586
 0.080          2.610           0.080              2.6118            17.7282           53.8882
 0.090          2.788           0.090              2.7909            18.1375           76.0353
 0.100          2.970           0.100              2.9753            18.7672           50.7999
 0.110          3.131           0.110              3.1672            19.6214           54.6356
 0.120          3.377           0.120              3.3674            20.3455           21.9592
 0.130          3.544           0.130              3.5732            20.7815          -31.1996
 0.140          3.751           0.140              3.7816            20.7853         -136.7472
 0.150          4.002           0.150              3.9861            19.9456         -220.2938
 0.160          4.153           0.160              4.1773            18.1602         -337.8276
 0.170          4.424           0.170              4.3460            15.3696         -346.0344
 0.180          4.554           0.180              4.4826            11.4563         -254.4365
 0.190          4.522           0.190              4.5864             8.9486         -113.5761
 0.200          4.642           0.200              4.6655             7.1076           -5.4313
 0.210          4.677           0.210              4.7327             6.5128           25.3736
 0.220          4.771           0.220              4.7960             6.6124           18.6921
 0.230          4.857           0.230              4.8653             6.8529

N.P.  DATA FOR SUBJECT 1, PITCH 1, TIME INTERVAL .01 SECONDS BETWEEN FRAMES
```

```
                     SEGMENTAL ANALYSIS PROGRAM-3 SEGMENTS

                     ANGULAR KINEMATICS OF THE LOWER ARM
                                                        OUTPUT
         INPUT
                                                 VELOCITY       ACCELRATION
   X            F          TIME    DISPLACEMENT                     0.0
0.0          0.667       0.0          0.6505     13.1992         22.9685
0.010        0.778       0.010        0.7829     13.3140         38.5824
0.020        0.912       0.020        0.9174     13.6217         46.8665
0.030        1.055       0.030        1.0557     14.0491         54.6966
0.040        1.197       0.040        1.1987     14.5569         60.6049
0.050        1.341       0.050        1.3471     15.1334         58.2844
0.060        1.521       0.060        1.5014     15.7278         92.9473
0.070        1.630       0.070        1.6620     16.4340         63.5527
0.080        1.843       0.080        1.8302     17.1665         61.3722
0.090        2.027       0.090        2.0050     17.7912         88.9782
0.100        2.120       0.100        2.1864     18.5428        107.8640
0.110        2.399       0.110        2.3766     19.5271        157.4227
0.120        2.595       0.120        2.5781     20.8535        230.3524
0.130        2.811       0.130        2.7957     22.7929        323.5630
0.140        3.018       0.140        3.0367     25.5620        391.0609
0.150        3.242       0.150        3.3097     29.1352        365.2881
0.160        3.554       0.160        3.6201     32.9171        243.9042
0.170        3.882       0.170        3.9656     35.9879         17.0814
0.180        4.340       0.180        4.3341     37.3180       -207.1953
0.190        4.737       0.190        4.7044     36.3674       -386.1921
0.200        5.174       0.200        5.0547     33.4003       -401.9875
0.210        5.417       0.210        5.3692     29.4695       -351.5923
0.220        5.731       0.220        5.6445     25.6915       -181.6606
0.230        5.895       0.230        5.8867     23.0251

N.B.  DATA FOR SUBJECT 1, PITCH 1, TIME INTERVAL .01 SECONDS BETWEEN FRAMES
```

```
                    SEGMENTAL ANALYSIS PROGRAM-3 SEGMENTS

                   ANGULAR KINEMATICS OF THE HAND SEGMENT

         INPUT                                           OUTPUT

    X          F          TIME        DISPLACEMENT      VELOCITY      ACCELERATION
  0.0        0.274       0.0            0.2938          16.3988          0.0
  0.010      0.489       0.010          0.4560          15.8467       -110.4183
  0.020      0.605       0.020          0.6102          15.1219        -34.5396
  0.030      0.773       0.030          0.7605          15.0242         14.9835
  0.040      0.888       0.040          0.9135          15.7751        135.1971
  0.050      1.070       0.050          1.0777          17.0307        115.9492
  0.060      1.241       0.060          1.2528          17.8816         54.2020
  0.070      1.469       0.070          1.4322          17.7599        -72.5318
  0.080      1.614       0.080          1.6077          17.4466          4.3249
  0.090      1.748       0.090          1.7843          18.0535        116.5997
  0.100      1.988       0.100          1.9692          18.7675         26.2058
  0.110      2.152       0.110          2.1584          19.1104         42.3841
  0.120      2.373       0.120          2.3513          19.4312         21.7660
  0.130      2.549       0.130          2.5483          20.1444        120.8604
  0.140      2.796       0.140          2.7576          21.8684        223.9246
  0.150      3.021       0.150          2.9927          25.6901        540.4126
  0.160      3.225       0.160          3.2845          33.4050       1014.5566
  0.170      3.617       0.170          3.6723          44.3320       1158.6643
  0.180      3.961       0.180          4.1709          55.1106        996.8496
  0.190      4.866       0.190          4.7496          58.4051       -337.9609
  0.200      5.465       0.200          5.2998          49.9368      -1355.6934
  0.210      5.855       0.210          5.7241          34.2177      -1788.1479
  0.220      6.035       0.220          5.9818          17.8082      -1493.7485
  0.230      6.151       0.230          6.0951           5.8297       -901.9375

N.B.  DATA FOR SUBJECT 1, PITCH 1, TIME INTERVAL .01 SECONDS BETWEEN FRAMES
```

LINEAR KINEMATICS OF SHOULDER

INPUT		OUTPUT			
X	P	TIME	DISPLACEMENT	VELOCITY	ACCELERATION
			X-COORDINATES OF SHOULDER		
0.0	0.323	0.0	0.3118	1.4521	0.0
0.010	0.332	0.010	0.3263	1.4610	1.7777
0.020	0.340	0.020	0.3411	1.4920	4.4141
0.030	0.355	0.030	0.3563	1.5485	6.8834
0.040	0.366	0.040	0.3721	1.6284	9.0969
0.050	0.387	0.050	0.3889	1.7257	10.3621
0.060	0.402	0.060	0.4067	1.8343	11.3675
0.070	0.413	0.070	0.4256	1.9493	11.6193
0.080	0.441	0.080	0.4456	2.0572	9.9570
0.090	0.469	0.090	0.4667	2.1448	7.5624
0.100	0.478	0.100	0.4885	2.2099	5.4502
0.110	0.521	0.110	0.5108	2.2460	1.7656
0.120	0.529	0.120	0.5333	2.2529	-0.3954
0.130	0.564	0.130	0.5557	2.2345	-3.2675
0.140	0.586	0.140	0.5779	2.1942	-4.7679
0.150	0.607	0.150	0.5996	2.1447	-5.1195
0.160	0.638	0.160	0.6208	2.0974	-4.3394
0.170	0.641	0.170	0.6416	2.0759	-0.9532
0.180	0.659	0.180	0.6623	2.0779	2.3447
0.190	0.670	0.190	0.6833	2.1151	5.0918
0.200	0.696	0.200	0.7047	2.1697	5.8207
0.210	0.724	0.210	0.7267	2.2249	5.2226
0.220	0.740	0.220	0.7492	2.2720	4.1964
0.230	0.776	0.230	0.7721	2.3020	1.8013

N.B. DATA FOR SUBJECT 1, PITCH 1, TIME INTERVAL .01 SECONDS BETWEEN FRAMES

LINEAR KINEMATICS OF SHOULDER

INPUT				OUTPUT	
X	F	TIME	DISPLACEMENT	VELOCITY	ACCELERATION
		Y-COORDINATES OF SHOULDER			
0.0	-0.062	0.0	-0.0598	-1.1526	0.0
0.010	-0.073	0.010	-0.0714	-1.1557	-0.6212
0.020	-0.081	0.020	-0.0830	-1.1674	-1.7040
0.030	-0.096	0.030	-0.0947	-1.1877	-2.3697
0.040	-0.106	0.040	-0.1067	-1.2164	-3.3527
0.050	-0.124	0.050	-0.1191	-1.2535	-4.0734
0.060	-0.130	0.060	-0.1319	-1.3035	-5.9245
0.070	-0.132	0.070	-0.1452	-1.3698	-7.3347
0.080	-0.153	0.080	-0.1592	-1.4334	-5.3834
0.090	-0.176	0.090	-0.1738	-1.4695	-1.8419
0.100	-0.187	0.100	-0.1885	-1.4726	1.2269
0.110	-0.202	0.110	-0.2031	-1.4433	4.6411
0.120	-0.205	0.120	-0.2173	-1.3786	8.4207
0.130	-0.231	0.130	-0.2305	-1.2594	15.2757
0.140	-0.246	0.140	-0.2422	-1.0729	22.0095
0.150	-0.252	0.150	-0.2516	-0.8234	27.9601
0.160	-0.272	0.160	-0.2585	-0.5153	33.6919
0.170	-0.272	0.170	-0.2619	-0.1666	36.1576
0.180	-0.275	0.180	-0.2618	0.1954	36.1116
0.190	-0.263	0.190	-0.2581	0.5400	32.7798
0.200	-0.267	0.200	-0.2511	0.8443	28.0910
0.210	-0.239	0.210	-0.2414	1.0820	19.4239
0.220	-0.225	0.220	-0.2298	1.2356	11.3355
0.230	-0.208	0.230	-0.2170	1.3154	4.5725

N.B. DATA FOR SUBJECT 1, PITCH 1, TIME INTERVAL .01 SECONDS BETWEEN FRAMES

LINEAR VELOCITIES AND ACCELERATIONS OF SEGMENTAL ENDPOINTS

ELBOW KINEMATICS

FRAME	X-VELOCITY	Y-VELOCITY	X-ACCELERATION	Y-ACCELERATION
1	-5.2134	1.9163	-37.0053	-100.6744
2	-5.6386	0.5715	-3.1106	-110.5247
3	-5.7460	-0.8255	27.1915	-111.3992
4	-5.5162	-2.1983	61.6449	-104.0400
5	-4.9971	-3.4715	86.2557	-90.8665
6	-4.2437	-4.5945	108.4592	-71.3561
7	-3.3537	-5.5716	115.1953	-60.8326
8	-2.3679	-6.4550	125.1492	-49.3380
9	-1.3475	-7.2465	133.0545	-38.4394
10	-0.2232	-7.9422	144.5785	-25.1210
11	1.0283	-8.5133	160.6080	-7.9561
12	2.4371	-8.8970	177.2245	17.9684
13	3.9840	-8.9141	185.6422	64.2538
14	5.5382	-8.4322	177.0463	119.3361
15	6.9111	-7.4033	142.1149	175.1674
16	7.8114	-5.8567	72.8447	218.2116
17	8.0338	-4.0339	-3.0945	222.2611
18	7.5237	-2.2565	-86.0903	197.7874
19	6.4947	-0.6388	-115.6703	143.7308
20	5.4984	0.1126	-91.8348	94.0316
21	4.8677	0.7177	-42.3918	64.7135
22	4.6995	1.1322	-4.2146	49.9877
23	4.7755	1.4508	4.2097	43.7412
24	4.8682	1.7109	-2.8652	38.9182

N.B. DATA FOR SUBJECT 1, PITCH 1, TIME INTERVAL .01 SECONDS BETWEEN FRAMES

LINEAR VELOCITIES AND ACCELERATIONS OF SEGMENTAL ENDPOINTS

KINEMATICS OF THE ARM CENTER OF GRAVITY

FRAME	X-VELOCITY	Y-VELOCITY	X-ACCELERATION	Y-ACCELERATION
1	-1.4541	0.1654	-37.0053	-100.6744
2	-1.6344	-0.4026	-6.5516	-109.6875
3	-1.6612	-1.0183	23.2159	-111.2113
4	-1.5317	-1.6283	54.0442	-105.1272
5	-1.2603	-2.1996	78.7981	-93.4249
6	-0.8770	-2.7162	99.7809	-76.7133
7	-0.4277	-3.1644	112.1911	-63.3641
8	0.0532	-3.5869	125.1507	-49.3363
9	0.5728	-3.9679	136.0829	-33.2666
10	1.1124	-4.2916	148.5465	-14.2747
11	1.6847	-4.5423	163.3653	8.1150
12	2.3293	-4.6531	176.7256	37.4222
13	3.0076	-4.6637	183.0207	80.6660
14	3.6749	-4.3867	174.1808	125.5594
15	4.2508	-3.8351	146.1082	169.3046
16	4.6154	-3.0179	94.7567	198.7487
17	4.6857	-2.0494	37.5206	193.1879
18	4.4483	-1.0763	-18.4934	171.8473
19	4.0053	-0.2555	-43.4569	126.8416
20	3.5858	0.3536	-37.7364	87.1877
21	3.3460	0.7891	-18.0769	63.5719
22	3.3037	1.1039	-3.0508	50.0113
23	3.3635	1.3295	-1.2084	43.2760
24	3.4269	1.4879	-6.8286	38.3080

N.B. DATA FOR SUBJECT 1, PITCH 1, TIME INTERVAL .01 SECONDS BETWEEN FRAMES

LINEAR VELOCITIES AND ACCELERATIONS OF SEGMENTAL ENDPOINTS

KINEMATICS OF THE LOWER ARM CENTER OF GRAVITY

FRAME	X-VELOCITY	Y-VELOCITY	X-ACCELERATION	Y-ACCELERATION
1	-6.2102	3.2261	-102.5626	-200.0828
2	-6.6096	1.7414	-49.1807	-219.8253
3	-7.0888	0.2670	[illegible].9978	-225.3956
4	-7.0469	-1.3353	59.2472	-228.4719
5	-6.6081	-2.6115	108.0937	-218.3949
6	-6.0836	-4.1756	155.6670	-199.1618
7	-5.3102	-5.4357	190.0008	-184.6373
8	-4.4267	-6.6417	22[illegible]651	-167.5205
9	-3.4165	-7.7955	271.7112	-146.2047
10	-2.2359	-8.6[illegible]	317.5510	-115.5859
11	-0.6595	-9.5400	360.9922	-76.7027
12	0.7508	-10.6536	421.4153	-20.7223
13	2.5950	-11.1126	467.6636	68.3779
14	4.5747	-11.1061	501.2313	167.4729
15	6.5[illegible]74	-10.5763	515.7124	291.6687
16	8.4191	-9.4357	494.3534	430.8984
17	9.9240	-7.6776	424.5935	590.9731
18	10.6172	-5.3066	273.0401	723.1091
19	10.6242	-2.5575	96.7725	760.8079
20	10.0252	0.0763	-116.6901	677.3816
21	8.7910	2.1158	-226.3257	515.3750
22	7.6887	3.3751	-259.5325	357.1440
23	6.6854	4.0230	-217.8626	245.3438
24	5.5771	4.3564	-192.3267	159.4921

N.B. DATA FOR SUBJECT 1, PITCH 1, TIME INTERVAL .01 SECONDS BETWEEN FRAMES

LINEAR VELOCITIES AND ACCELERATIONS OF SEGMENTAL ENDPOINTS

WRIST KINEMATICS

FRAME	X-VELOCITY	Y-VELOCITY	X-ACCELERATION	Y-ACCELERATION
1	-7.5315	4.9523	-102.5036	-200.0838
2	-8.3619	3.3085	-51.8566	-217.1340
3	-8.8767	1.5757	-3.1565	-225.5138
4	-9.0619	-0.1914	52.5052	-224.6557
5	-8.9297	-1.9367	99.6711	-215.1077
6	-8.5230	-3.6209	146.1187	-196.9395
7	-7.9038	-5.2554	180.9887	-183.9699
8	-7.1340	-6.8891	214.4109	-168.7697
9	-6.1592	-8.5234	261.5574	-148.8992
10	-4.9039	-10.1127	308.3484	-119.8537
11	-3.3619	-11.6186	354.9844	-85.1964
12	-1.4845	-12.9822	409.0679	-33.5850
13	0.7538	-14.0207	453.7646	46.3788
14	3.2975	-14.6506	488.3230	131.6503
15	6.1352	-14.7835	510.1145	233.6776
16	9.2248	-14.1869	505.1516	375.1670
17	12.4296	-12.5076	457.3987	537.3740
18	15.1830	-9.3476	303.2854	695.1616
19	16.5567	-4.8358	69.3964	759.7651
20	16.0345	0.0282	-152.9464	677.6558
21	13.9917	3.9691	-280.4590	494.4458
22	11.4653	6.3483	-283.5576	316.5737
23	9.2172	7.4326	-247.5301	199.6819
24	7.4471	7.8701	-264.4267	161.7927

N.B. DATA FOR SUBJECT 1, PITCH 1, TIME INTERVAL .01 SECONDS BETWEEN FRAMES

LINEAR VELOCITIES AND ACCELERATIONS OF SEGMENTAL ENDPOINTS

KINEMATICS OF THE LOWER ARM CENTER OF GRAVITY

FRAME	X-VELOCITY	Y-VELOCITY	X-ACCELERATION	Y-ACCELERATION
1	-6.2102	3.2261	-102.5036	-200.0838
2	-6.6096	1.7484	-49.1807	-219.8253
3	-7.0886	0.2070	1.9078	-229.3906
4	-7.0409	-1.3353	59.2472	-228.4719
5	-6.6881	-2.8115	108.0937	-218.3949
6	-6.0438	-4.1759	155.8870	-199.1618
7	-5.3102	-5.4357	190.6008	-184.6373
8	-4.4287	-6.6417	228.0651	-167.5205
9	-3.4165	-7.7955	271.7112	-146.2047
10	-2.2359	-8.8755	317.5518	-115.5859
11	-0.6595	-9.8486	366.9922	-76.7027
12	0.7508	-10.6536	421.4153	-20.7223
13	2.5950	-11.1126	467.6636	68.3779
14	4.5747	-11.1061	501.2310	167.4729
15	6.5774	-10.5783	515.7124	291.8687
16	8.4191	-9.4387	494.3384	438.8934
17	9.9240	-7.6776	429.5935	590.9731
18	10.6172	-5.3068	273.0901	723.1091
19	10.8242	-2.5575	56.7725	760.3979
20	10.0232	0.0763	-118.6961	677.3816
21	8.7910	2.1158	-220.3257	515.8750
22	7.6087	3.3751	-230.9323	357.1440
23	6.6854	4.0230	-212.8829	245.3434
24	5.9771	4.3594	-192.8287	189.4921

N.B. DATA FOR SUBJECT 7, PITCH 1, TIME INTERVAL .01 SECONDS BETWEEN FRAMES

LINEAR VELOCITIES AND ACCELERATIONS OF SEGMENTAL ENDPOINTS

FINGERTIP KINEMATICS

FRAME	X-VELOCITY	Y-VELOCITY	X-ACCELERATION	Y-ACCELERATION
1	-8.2615	7.3748	-223.4413	-237.9818
2	-9.4344	5.4953	-131.4686	-216.6007
3	-10.2085	3.4805	-52.7461	-161.8802
4	-10.6536	1.4817	28.6573	-105.8871
5	-10.8491	-0.4553	90.4028	-58.7781
6	-10.8288	-2.3818	170.9847	-29.3673
7	-10.5143	-4.3960	251.6834	-4.4193
8	-9.8421	-6.5113	341.2876	37.7810
9	-8.8393	-8.6224	411.3433	107.2978
10	-7.6157	-10.7066	484.0176	167.0617
11	-6.0206	-12.7376	590.3245	240.4307
12	-3.9290	-14.6106	682.8604	330.3766
13	-1.3683	-16.1282	764.7771	424.8225
14	1.5066	-17.2177	824.7771	504.4763
15	4.8759	-17.8969	888.5957	584.3319
16	9.6391	-18.0917	957.6096	644.9475
17	13.1624	-17.5987	1068.5527	743.5308
18	18.6319	-15.2241	1068.3582	975.6587
19	23.8154	-9.2618	707.8059	1302.9036
20	25.0052	0.3620	-225.9999	1305.5513
21	20.3806	8.2227	-864.5176	621.8357
22	14.2547	10.8069	-799.1111	-28.7947
23	10.0296	10.0464	-494.5250	-288.1631
24	7.6146	8.7563	-231.3611	-296.2178

N.B. DATA FOR SUBJECT 1, PITCH 1, TIME INTERVAL .01 SECONDS BETWEEN FRAMES

LINEAR VELOCITIES AND ACCELERATIONS OF SEGMENTAL ENDPOINTS

KINEMATICS OF THE HAND CENTER OF GRAVITY

FRAME	X-VELOCITY	Y-VELOCITY	X-ACCELERATION	Y-ACCELERATION
1	-7.7355	5.3378	-223.4413	-237.9818
2	-8.6627	3.9208	-136.8491	-205.6298
3	-9.2496	2.1090	-54.9363	-158.7477
4	-9.5675	0.2771	29.8002	-107.0884
5	-9.4671	-1.5219	102.2469	-67.9193
6	-9.1666	-3.2740	132.2574	-35.9413
7	-8.6347	-5.0148	257.3606	-5.2949
8	-7.8923	-6.7234	333.3381	38.3901
9	-6.9595	-8.5511	411.8214	107.3155
10	-5.6632	-10.2773	496.6279	169.7958
11	-4.1063	-11.9319	592.9970	241.5556
12	-2.1645	-13.4262	686.7639	332.9709
13	0.1566	-14.6152	766.4365	426.5173
14	2.7329	-15.3698	832.2556	515.5676
15	5.7826	-15.6551	897.9801	657.3071
16	8.0690	-15.2802	965.4407	704.0901
17	12.0234	-12.9331	1052.5586	851.6604
18	10.1467	-10.9930	1003.4458	1096.2620
19	11.5552	-6.0573	613.2732	1459.7634
20	14.5063	0.1217	-188.6256	1306.9419
21	15.7806	5.1691	-739.6365	704.9480
22	12.2063	7.5967	-694.1597	138.9641
23	9.6646	8.1645	-445.5195	-130.3036
24	7.8986	8.1156	-262.6968	-198.1666

N.B. DATA FOR SUBJECT 1, PITCH 1, TIME INTERVAL .01 SECONDS BETWEEN FRAMES

KINETICS OF THE UPPER EXTREMITY

FORCES AND MOMENTS AT THE ELBOW JOINT

FRAME	X-JOINT FORCES	Y-JOINT FORCES	MOMENT AT THE JOINT
1	-403.23877	-584.67627	1.07954
2	-219.49855	-605.78149	3.43687
3	-44.38028	-577.05864	7.00162
4	145.84396	-526.04102	17.56139
5	308.12207	-464.32373	31.99353
6	474.94019	-400.68936	53.40491
7	610.99341	-348.40747	75.64864
8	753.36206	-276.77856	99.36859
9	910.43604	-172.68480	125.36574
10	1077.49390	-58.36252	151.90668
11	1261.97607	84.59961	178.48724
12	1454.23755	276.64673	199.83279
13	1617.65723	539.55811	209.28883
14	1743.20679	809.66602	200.40227
15	1830.07788	1131.49756	172.04547
16	1847.13379	1481.27954	111.89008
17	1791.92529	1875.02637	21.93678
18	1432.66748	2345.74951	-60.74275
19	673.33423	2709.22217	-63.51706
20	-405.38330	2543.02612	55.40456
21	-1094.45850	1616.45361	149.53146
22	-1075.95557	724.59009	144.16599
23	-821.18945	271.02734	109.17807
24	-620.16162	151.13603	78.56841

N.B. DATA FOR SUBJECT 1, PITCH 1, TIME INTERVAL .01 SECONDS BETWEEN FRAMES

KINETICS OF THE UPPER EXTREMITY

FORCES AND MOMENTS AT THE SHOULDER JOINT

FRAME	X-JOINT FORCES	Y-JOINT FORCES	MOMENT AT THE JOINT
1	-533.49731	-939.05029	-275.18384
2	-242.56030	-991.88159	-151.65672
3	37.33957	-968.52246	-10.63072
4	336.07935	-896.00887	138.86422
5	585.49121	-793.17944	258.97681
6	826.16895	-670.12012	355.53906
7	1005.90625	-571.23779	412.16797
8	1193.89258	-450.44214	434.42212
9	1389.44775	-289.79102	415.03467
10	1600.37769	-108.60956	353.59009
11	1836.01055	113.16451	240.91724
12	2076.31177	408.37280	60.49261
13	2261.68989	823.50244	-195.26965
14	2356.32324	1251.63501	-463.64111
15	2344.37842	1729.20752	-719.95508
16	2180.67725	2180.87500	-911.58325
17	1923.99756	2572.64771	-1015.50049
18	1367.57056	2950.65186	-930.49512
19	520.36572	3155.70459	-555.96045
20	-538.21533	2849.92676	89.94836
21	-1158.08911	1640.22681	539.47754
22	-1086.69469	900.62964	560.65820
23	-825.44267	423.35889	432.98071
24	-644.19800	285.97998	328.46851

N.B. DATA FOR SUBJECT 1, PITCH 1, TIME INTERVAL .01 SECONDS BETWEEN FRAMES

```
                 SEGMENTAL ANALYSIS PROGRAM-3 SEGMENTS
                  ANGULAR KINEMATICS OF THE UPPER ARM

                                                    OUTPUT
          INPUT
                                                      VELOCITY      ACCELERATION
   X          F          TIME       DISPLACEMENT
 0.0        -1.901       0.0          -1.9149         7.0076          0.0
 0.020      -1.754       0.020        -1.7737         7.1565         14.8919
 0.040      -1.630       0.040        -1.6252         7.8110         50.5462
 0.060      -1.450       0.060        -1.4569         9.1252         80.8744
 0.080      -1.268       0.080        -1.2557        11.1146        118.0747
 0.100      -1.022       0.100        -1.0082        13.7207        142.5341
 0.120      -0.732       0.120        -0.7046        16.6674        152.1332
 0.140      -0.368       0.140        -0.3422        19.5081        131.9437
 0.160      -0.014       0.160         0.0712        21.6715         84.3933
 0.180       0.582       0.180         0.5122        21.9630        -55.2460
 0.200       1.006       0.200         0.9361        20.2068       -120.3643
 0.220       1.363       0.220         1.3168        17.9042       -109.8866
 0.240       1.655       0.240         1.6570        16.3114        -49.4066
 0.260       1.962       0.260         1.9772        15.9099          9.2643
 0.280       2.286       0.280         2.3001        16.5232         52.0677
 0.300       2.610       0.300         2.6429        17.8432         79.9217
 0.320       2.957       0.320         3.0152        19.3666         72.4272
 0.340       3.370       0.340         3.4123        20.1121          2.1223
 0.360       3.802       0.360         3.8073        18.9953       -113.6077
 0.380       4.293       0.380         4.1563        15.5035       -235.3732
 0.400       4.493       0.400         4.4210        11.0495       -210.0231
 0.420       4.592       0.420         4.6068         7.8783       -107.0966
 0.440       4.723       0.440         4.7488         6.6019        -20.5303
 0.460       4.791       0.460         4.8806         6.7769         38.0166

N.B.  DATA FOR SUBJECT 2, PITCH 1, TIME INTERVAL .02 SECONDS BETWEEN FRAMES
```

```
                    SEGMENTAL ANALYSIS PROGRAM-3 SEGMENTS

                   ANGULAR KINEMATICS OF THE LOWER ARM

          INPUT                                        OUTPUT

  X          F          TIME      DISPLACEMENT     VELOCITY     ACCELERATION
0.0        -1.337      0.0          -1.3432         7.3503          0.0
0.020      -1.195      0.020        -1.1953         7.4763         12.5952
0.040      -1.028      0.040        -1.0424         7.8582         25.5936
0.060      -0.930      0.060        -0.8773         8.7966         68.2461
0.080      -0.703      0.080        -0.6919         9.5353          5.6235
0.100      -0.461      0.100        -0.5057         8.7988        -79.2715
0.120      -0.332      0.120        -0.3452         7.2700        -73.6124
0.140      -0.204      0.140        -0.2124         6.1243        -40.9531
0.160      -0.072      0.160        -0.0947         5.8087          9.3876
0.180       0.013      0.180         0.0297         6.9545        105.1958
0.200       0.187      0.200         0.1939         9.6726        160.6198
0.220       0.384      0.220         0.4239        13.4885        214.9616
0.240       0.714      0.240         0.7345        17.4637        182.5631
0.260       1.121      0.260         1.1154        20.3791        108.9757
0.280       1.577      0.280         1.5407        21.9424         47.3549
0.300       2.012      0.300         1.9898        23.0040         58.8014
0.320       2.472      0.320         2.4653        24.7341        114.2130
0.340       2.956      0.340         2.9875        27.7157        183.9480
0.360       3.488      0.360         3.5790        31.4580        190.2807
0.380       4.149      0.380         4.2345        33.5045         14.3650
0.400       5.002      0.400         4.8843        30.3199       -332.8220
0.420       5.494      0.420         5.4168        22.5566       -443.5076
0.440       5.860      0.440         5.7821        14.1221       -399.9407
0.460       5.998      0.460         5.9979         8.1217       -200.0961

N.B.  DATA FOR SUBJECT 2, PITCH 1, TIME INTERVAL .02 SECONDS BETWEEN FRAMES
```

```
                         SEGMENTAL ANALYSIS PROGRAM-3 SEGMENTS

                        ANGULAR KINEMATICS OF THE HAND SEGMENT

        INPUT                                                 OUTPUT

  X            P           TIME         DISPLACEMENT       VELOCITY       ACCELERATION
0.0         -0.901         0.0            -0.9328           5.2447           0.0
0.020       -0.827         0.020          -0.8241           5.8064          56.1674
0.040       -0.761         0.040          -0.6934           7.4346         106.6547
0.060       -0.569         0.060          -0.5281           8.8520          35.0883
0.080       -0.304         0.080          -0.3537           8.1084        -109.4494
0.100       -0.172         0.100          -0.2171           5.3742        -163.9747
0.120       -0.099         0.120          -0.1407           2.3552        -137.9184
0.140       -0.104         0.140          -0.1144           0.6119         -36.4123
0.160       -0.091         0.160          -0.1014           1.0887          84.0947
0.180       -0.134         0.180          -0.0535           4.1694         223.9700
0.200        0.074         0.200           0.0744           8.5963         218.7207
0.220        0.275         0.220           0.2896          12.9050         212.1434
0.240        0.558         0.240           0.5879          16.8142         178.7752
0.260        0.944         0.260           0.9541          19.5126          91.0670
0.280        1.430         0.280           1.3555          20.2723         -15.0915
0.300        1.848         0.300           1.7598          20.2470          12.5654
0.320        2.154         0.320           2.1796          22.3577         198.4966
0.340        2.649         0.340           2.6758          27.7320         338.9265
0.360        3.166         0.360           3.3044          35.4376         431.6318
0.380        3.848         0.380           4.0891          42.5071         275.3147
0.400        5.059         0.400           4.9550          42.1158        -314.4382
0.420        5.961         0.420           5.7075          31.7965        -717.4834
0.440        6.384         0.440           6.2035          17.9714        -665.0220
0.460        6.406         0.460           6.4550           8.4405        -288.0718

N.B.  DATA FOR SUBJECT 2, PITCH 1, TIME INTERVAL .02 SECONDS BETWEEN FRAMES
```

```
                          LINEAR KINEMATICS OF SHOULDER

                                                            OUTPUT
          INPUT
                                                     VELOCITY        ACCELERATION
  X               F          TIME      DISPLACEMENT

                             X-COORDINATES OF SHOULDER
                                          0.4052
0.0             0.409       0.0           0.4195         0.7150          0.0
0.020           0.418       0.020         0.4339         0.7167          0.1681
0.040           0.436       0.040         0.4484         0.7208          0.2471
0.060           0.448       0.060         0.4630         0.7277          0.4355
0.080           0.465       0.080         0.4779         0.7380          0.5966
0.100           0.479       0.100         0.4932         0.7525          0.8519
0.120           0.493       0.120         0.5089         0.7728          1.1787
0.140           0.524       0.140         0.5252         0.7993          1.4742
0.160           0.539       0.160         0.5426         0.8387          2.4664
0.180           0.537       0.180         0.5616         0.9040          4.0662
0.200           0.557       0.200         0.5827         0.9968          5.4133
0.220           0.576       0.220         0.6065         1.1186          6.5637
0.240           0.600       0.240         0.6332         1.2582          7.4056
0.260           0.619       0.260         0.6630         1.4120          7.9739
0.280           0.637       0.280         0.6959         1.5708          7.9074
0.300           0.691       0.300         0.7314         1.7162          6.6274
0.320           0.739       0.320         0.7691         1.8337          5.1322
0.340           0.773       0.340         0.8083         1.9247          3.9642
0.360           0.821       0.360         0.8488         1.9944          2.4999
0.380           0.853       0.380         0.8903         2.0505          2.6035
0.400           0.880       0.400         0.9327         2.1003          2.3785
0.420           0.927       0.420         0.9758         2.1408          1.6738
0.440           0.976       0.440         1.0192         2.1647          0.7213
0.460           1.044       0.460                        2.1699         -0.2081

N.B.  DATA FOR SUBJECT 2, PITCH 1, TIME INTERVAL .02 SECONDS BETWEEN FRAMES
```

LINEAR KINEMATICS OF SHOULDER

INPUT				OUTPUT	
X	F	TIME	DISPLACEMENT	VELOCITY	ACCELERATION
		Y-COORDINATES OF SHOULDER			
0.0	0.360	0.0	0.3435	-0.2709	0.0
0.020	0.323	0.020	0.3396	-0.0445	22.6382
0.040	0.333	0.040	0.3432	0.4008	21.8954
0.060	0.357	0.060	0.3546	0.6856	6.5820
0.080	0.376	0.080	0.3688	0.6988	-5.2672
0.100	0.383	0.100	0.3816	0.5709	-7.5223
0.120	0.385	0.120	0.3915	0.4173	-7.8386
0.140	0.399	0.140	0.3976	0.1614	-17.7467
0.160	0.413	0.160	0.3967	-0.2747	-25.8652
0.180	0.380	0.180	0.3870	-0.6456	-11.2225
0.200	0.374	0.200	0.3722	-0.8190	-6.1210
0.220	0.347	0.220	0.3552	-0.8606	1.9657
0.240	0.334	0.240	0.3381	-0.8526	-1.1624
0.260	0.325	0.260	0.3203	-0.9625	-9.8343
0.280	0.315	0.280	0.2989	-1.1755	-11.4617
0.300	0.269	0.300	0.2745	-1.1949	9.5175
0.320	0.249	0.320	0.2535	-0.8668	23.2910
0.340	0.238	0.340	0.2413	-0.3233	31.0634
0.360	0.233	0.360	0.2412	0.3248	33.7419
0.380	0.256	0.380	0.2539	0.9174	25.5204
0.400	0.284	0.400	0.2770	1.3782	20.5579
0.420	0.289	0.420	0.3090	1.8311	24.7341
0.440	0.356	0.440	0.3491	2.0982	1.9754
0.460	0.409	0.460	0.3905	2.0014	-11.6509

N.B. DATA FOR SUBJECT 2, PITCH 1, TIME INTERVAL .02 SECONDS BETWEEN FRAMES

LINEAR VELOCITIES AND ACCELERATIONS OF SEGMENTAL ENDPOINTS

ELBOW KINEMATICS

FRAME	X-VELOCITY	Y-VELOCITY	X-ACCELERATION	Y-ACCELERATION
1	2.7600	-1.0037	7.0334	19.3414
2	2.8897	-0.4916	8.2081	42.3879
3	3.1386	0.2691	13.7915	45.5585
4	3.5381	1.0071	16.1536	41.7178
5	4.0139	1.7665	15.7643	50.6884
6	4.3503	2.8396	-0.7345	75.7350
7	4.1196	4.3537	-40.8368	96.7545
8	2.8286	5.8563	-99.0846	75.9645
9	0.3609	6.4264	-138.6644	8.0512
10	-2.4327	5.2892	-103.7080	-79.5806
11	-4.0452	2.8954	-23.0471	-109.9883
12	-4.2537	0.5340	29.9749	-82.7524
13	-3.7795	-1.2877	43.6683	-61.4937
14	-3.1183	-2.9122	51.6695	-60.5815
15	-2.2485	-4.5887	71.6926	-59.3693
16	-0.9296	-6.0525	102.7722	-28.8273
17	1.0769	-6.8226	134.4324	21.8744
18	3.5922	-6.3309	131.4733	102.6754
19	5.6311	-4.3066	63.0156	168.4551
20	6.1324	-1.6196	-34.2556	159.1101
21	5.3812	0.3941	-64.3400	98.7226
22	4.5695	1.5736	-43.7401	64.2314
23	4.2100	2.1726	-19.9823	29.5381
24	4.2411	2.3531	-4.5362	19.0634

N.B. DATA FOR SUBJECT 2, PITCH 1, TIME INTERVAL .02 SECONDS BETWEEN FRAMES

LINEAR VELOCITIES AND ACCELERATIONS OF SEGMENTAL ENDPOINTS

KINEMATICS OF THE ARM CENTER OF GRAVITY

FRAME	X-VELOCITY	Y-VELOCITY	X-ACCELERATION	Y-ACCELERATION
1	1.6066	-0.5904	7.0334	19.3414
2	1.6641	-0.2394	5.6578	42.9126
3	1.7750	0.3424	4.9670	46.0394
4	1.9530	0.8258	2.1052	40.1106
5	2.1663	1.1643	-3.8637	44.2911
6	2.3211	1.5600	-21.8141	62.4425
7	2.2320	2.1335	-58.0662	76.4900
8	1.6841	2.6452	-106.8256	54.2330
9	0.6304	2.6470	-137.6149	-6.6667
10	-0.5508	1.9420	-108.4418	-71.1609
11	-1.2004	0.8005	-39.9933	-97.5090
12	-1.2237	-0.2525	11.3787	-77.9251
13	-0.9382	-1.0423	35.0621	-62.2370
14	-0.5632	-1.8126	53.1573	-59.9411
15	-0.0944	-2.6636	78.4805	-53.3031
16	0.5626	-3.3128	109.4560	-16.5560
17	1.5038	-3.4635	136.0286	34.4366
18	2.6517	-2.9426	131.3740	103.0330
19	3.5800	-1.6945	75.3045	152.8052
20	3.8302	-0.1887	0.6926	137.3872
21	3.5308	0.9491	-29.1667	88.1730
22	3.1997	1.7189	-25.1195	62.2587
23	3.0565	2.1306	-16.3951	29.6687
24	3.0729	2.1548	-11.0392	17.9506

N.B. DATA FOR SUBJECT 2, PITCH 1, TIME INTERVAL .02 SECONDS BETWEEN FRAMES

LINEAR VELOCITIES AND ACCELERATIONS OF SEGMENTAL ENDPOINTS

WRIST KINEMATICS

FRAME	X-VELOCITY	Y-VELOCITY	X-ACCELERATION	Y-ACCELERATION
1	4.6934	-0.5559	11.1192	53.8398
2	4.7677	0.2486	9.5135	79.2793
3	4.9710	1.3387	9.2399	88.1052
4	5.3646	2.5253	8.1096	100.6867
5	5.6565	3.7489	-19.0141	105.7935
6	5.5012	4.9179	-54.3750	105.4149
7	4.7839	6.2007	-92.6420	112.8307
8	3.1771	7.4747	-147.1927	84.6133
9	0.5092	7.9877	-184.8226	13.5325
10	-2.4885	7.1661	-154.3883	-68.4964
11	-4.5485	5.4581	-84.5109	-109.8405
12	-5.7518	3.8535	-45.8773	-107.4331
13	-6.9398	2.2117	-27.9935	-146.1072
14	-8.0599	-0.4923	35.2766	-211.8950
15	-8.1702	-4.4103	155.6856	-238.2586
16	-6.6035	-8.5793	285.6262	-187.1924
17	-3.1030	-12.0309	412.7046	-78.9257
18	2.4434	-13.7255	504.2603	121.3192
19	9.2290	-12.0006	462.2915	412.2417
20	14.1651	-5.7801	162.8420	631.9207
21	13.4469	1.7945	-207.2876	491.0581
22	9.2104	5.5176	-259.4475	194.4436
23	6.0417	5.5168	-149.7647	20.1511
24	4.8583	4.4573	-55.9435	6.6792

N.B. DATA FOR SUBJECT 2, PITCH 1, TIME INTERVAL .02 SECONDS BETWEEN FRAMES

LINEAR VELOCITIES AND ACCELERATIONS OF SEGMENTAL ENDPOINTS

KINEMATICS OF THE LOWER ARM CENTER OF GRAVITY

FRAME	X-VELOCITY	Y-VELOCITY	X-ACCELERATION	Y-ACCELERATION
1	3.5914	-0.8111	11.1192	53.8398
2	3.6972	-0.1733	7.7101	78.5685
3	3.9266	0.7290	5.6382	86.1196
4	4.3235	1.6600	0.0325	93.9730
5	4.7202	2.6189	-19.5663	105.1271
6	4.8452	3.7333	-48.4647	116.0876
7	4.4053	5.1479	-88.8081	123.4911
8	2.9785	6.5533	-145.8641	90.7744
9	0.4247	7.0978	-184.9592	12.0942
10	-2.4567	6.0963	-153.9074	-84.6769
11	-4.2616	3.9973	-79.5691	-135.0026
12	-4.8979	1.9614	-32.2689	-137.5871
13	-5.1385	0.2171	-9.1621	-166.9588
14	-5.2432	-1.8717	50.3389	-219.2711
15	-4.7948	-4.5120	162.9704	-238.4781
16	-3.3694	-7.1390	293.8931	-183.5109
17	-0.7264	-9.0622	423.7063	-65.2171
18	3.0982	-9.5106	508.6060	149.2932
19	7.1782	-7.6150	449.8970	438.7690
20	9.5865	-3.4086	160.8789	632.9375
21	8.8495	0.9463	-156.8213	499.8206
22	6.5651	3.2696	-207.4353	238.6432
23	4.9976	3.6106	-120.1968	74.1349
24	4.5065	3.2579	-47.2761	36.2290

N.B. DATA FOR SUBJECT 2, PITCH 1, TIME INTERVAL .02 SECONDS BETWEEN FRAMES

LINEAR VELOCITIES AND ACCELERATIONS OF SEGMENTAL ENDPOINTS

FINGERTIP KINEMATICS

FRAME	X-VELOCITY	Y-VELOCITY	X-ACCELERATION	Y-ACCELERATION
1	5.2934	-0.1116	11.7015	38.8812
2	5.3745	0.8102	10.6797	46.1523
3	5.6477	2.1529	2.9413	62.9067
4	5.9998	3.6141	-21.3647	65.5361
5	6.0564	4.8321	-63.5934	15.4731
6	5.6660	5.6652	-89.8497	-46.7270
7	4.8309	6.5328	-110.7814	-100.7099
8	3.1871	7.5613	-152.4111	-150.3937
9	0.5249	8.1420	-192.4751	-172.3375
10	-2.4568	7.7590	-185.0345	-132.7838
11	-4.6395	6.6788	-144.2383	-93.3336
12	-6.2766	5.6146	-126.9611	-97.9249
13	-8.2676	4.2040	-112.6000	-145.8263
14	-10.3267	1.1147	2.9468	-158.7236
15	-10.9903	-3.7936	234.6898	-67.5732
16	-9.4353	-9.1209	468.5391	94.2525
17	-5.7147	-13.8517	699.2097	268.7715
18	0.6699	-17.2538	961.0679	479.7151
19	10.0471	-16.9801	1073.9905	757.6855
20	19.0799	-9.3133	590.5554	950.9883
21	19.2686	3.2352	-387.0054	593.4683
22	11.6752	9.3157	-611.2722	26.0769
23	6.2455	8.0676	-302.2957	-131.9233
24	4.6528	5.6416	-96.5465	-57.0894

N.B. DATA FOR SUBJECT 2, PITCH 1, TIME INTERVAL .02 SECONDS BETWEEN FRAMES

LINEAR VELOCITIES AND ACCELERATIONS OF SEGMENTAL ENDPOINTS

KINEMATICS OF THE HAND CENTER OF GRAVITY

FRAME	X-VELOCITY	Y-VELOCITY	X-ACCELERATION	Y-ACCELERATION
1	4.8614	-0.4313	11.7015	38.8812
2	4.9376	0.4058	6.4530	42.2409
3	5.1605	1.5666	-4.0479	54.4987
4	5.5425	2.8302	-23.1776	62.4287
5	5.7665	4.0522	-59.7063	26.0000
6	5.5473	5.1271	-86.2288	-30.3095
7	4.7971	6.2937	-108.7990	-86.7090
8	3.1799	7.4989	-151.9851	-146.6848
9	0.5136	8.0309	-193.3477	-180.9153
10	-2.4796	7.3321	-186.2615	-155.7141
11	-4.5740	5.7999	-142.5719	-115.6966
12	-5.8987	4.3466	-120.7496	-148.7698
13	-7.3117	2.7695	-102.6340	-161.0783
14	-8.6946	-0.0423	10.5638	-164.1236
15	-8.9599	-4.2376	233.1782	-67.2427
16	-7.3964	-8.7309	469.8044	94.4945
17	-3.8343	-12.5407	715.9045	280.4104
18	1.9468	-14.7134	976.6741	510.7629
19	9.4581	-13.3948	1066.8159	801.3545
20	15.5413	-6.7694	567.6360	967.4651
21	15.0770	2.1979	-355.7107	601.2126
22	9.9005	6.5611	-571.2268	87.7856
23	6.0987	6.2311	-296.8662	-63.9564
24	4.8007	4.7889	-101.5969	-27.9890

N.B. DATA FOR SUBJECT 2, PITCH 1, TIME INTERVAL .02 SECONDS BETWEEN FRAMES

KINETICS OF THE UPPER EXTREMITY

FORCES AND MOMENTS AT THE WRIST JOINT

FRAME	X-JOINT FORCES	Y-JOINT FORCES	MOMENT AT THE JOINT
1	6.42415	26.73364	0.42913
2	3.54272	30.72546	0.82501
3	-2.22227	39.92473	1.46436
4	-12.72451	41.36717	1.74067
5	-32.77875	13.88259	0.78372
6	-47.33963	-20.26521	-0.66456
7	-59.73067	-49.90181	-1.87338
8	-83.43982	-77.17825	-2.74013
9	-106.14787	-89.22537	-2.96637
10	-102.25754	-67.51038	-2.08485
11	-78.27199	-45.85223	-1.67887
12	-66.29155	-48.37288	-2.23835
13	-56.34608	-74.67076	-3.41593
14	5.79955	-81.75139	-1.53988
15	128.01485	-31.70981	4.69028
16	257.92261	57.13251	9.69453
17	393.03149	152.94342	9.70918
18	536.19385	268.75122	0.61025
19	585.68188	421.35693	-19.62160
20	311.63208	527.48022	-21.89188
21	-195.28517	331.20166	10.18982
22	-313.60352	19.70517	6.23188
23	-162.97955	-67.03799	-3.29081
24	-55.77667	-25.95418	-1.89536

N.B. DATA FOR SUBJECT 2, PITCH 1, TIME INTERVAL .02 SECONDS BETWEEN FRAMES

KINETICS OF THE UPPER EXTREMITY

FORCES AND MOMENTS AT THE ELBOW JOINT

FRAME	X-JOINT FORCES	Y-JOINT FORCES	MOMENT AT THE JOINT
1	19.32242	100.57198	-2.88934
2	12.48642	133.24916	-3.01117
3	4.55005	151.20763	-3.25714
4	-12.68681	161.76001	-2.23812
5	-55.47565	147.21425	3.58668
6	-103.55669	125.78056	9.71175
7	-162.74605	104.73212	15.70343
8	-252.64218	39.50423	22.06735
9	-320.70044	-63.81187	23.79872
10	-280.79004	-154.35364	16.11430
11	-170.57210	-191.07097	7.66270
12	-103.72345	-196.58969	3.93733
13	-66.97412	-256.95850	2.73734
14	64.19261	-324.72144	10.40244
15	317.06030	-296.95972	39.85628
16	598.83838	-144.35587	80.03282
17	884.53052	88.67580	109.20313
18	1126.17651	453.31519	95.93506
19	1107.55054	941.71269	17.89566
20	498.25146	1273.07[illegible]53	-30.99539
21	-377.19775	922.37744	44.31221
22	-554.22827	307.91528	63.93832
23	-302.40771	30.34268	30.68355
24	-110.61696	27.45573	7.54690

N.B. DATA FOR SUBJECT 2, PITCH 1, TIME INTERVAL .02 SECONDS BETWEEN FRAMES

```
                    KINETICS OF THE UPPER EXTREMITY


                    FORCES AND MOMENTS AT THE SHOULDER JOINT

FRAME   X-JOINT FORCES    Y-JOINT FORCES     MOMENT AT THE JOINT
  1          34.65518          142.73619           -22.91824
  2          24.82045          226.79869           -19.02849
  3          15.37820          251.57349            -8.46527
  4          -8.09750          249.20114             9.61666
  5         -63.89845          243.76894            41.42580
  6        -151.11336          261.90503            75.59497
  7        -289.33228          271.48022           104.23155
  8        -485.52197          157.73215            87.98000
  9        -620.70093          -78.34538            -6.26047
 10        -517.19312         -309.48438          -103.22878
 11        -257.75732         -403.64036           -98.82651
 12         -78.91788         -366.46631           -47.08772
 13           9.46130         -392.63501            -0.15131
 14         180.07561         -455.39307            90.01830
 15         488.14771         -413.16040           203.17328
 16         837.45239         -180.44798           229.34012
 17        1181.07275          163.74748           112.84683
 18        1412.57178          677.92700          -172.40680
 19        1271.71411         1274.82813          -475.00586
 20         499.76123         1572.57568          -396.46948
 21        -440.78101         1114.59448            70.98665
 22        -608.98877          443.63916           228.15062
 23        -338.14893           95.02036           129.46938
 24        -134.79138           66.58809            47.60049

N.B.  DATA FOR SUBJECT 2, PITCH 1, TIME INTERVAL .02 SECONDS BETWEEN FRAMES
```

```
                    SEGMENTAL ANALYSIS PROGRAM-3 SEGMENTS
                     ANGULAR KINEMATICS OF THE UPPER ARM

        INPUT                                                  OUTPUT

  X          F          TIME          DISPLACEMENT        VELOCITY         ACCELERATION
0.0        -1.192      0.0              -1.2268            7.3075             0.0
0.020      -1.091      0.020            -1.0790            7.5634            25.5915
0.040      -0.914      0.040            -0.9215            8.2425            42.3129
0.060      -0.737      0.060            -0.7467            9.3119            64.6329
0.080      -0.549      0.080            -0.5456           10.8959            93.7690
0.100      -0.308      0.100            -0.3071           13.0379           120.4348
0.120      -0.082      0.120            -0.0205           15.7102           146.7868
0.140       0.260      0.140             0.3218           18.4589           128.0873
0.160       0.676      0.160             0.7123           20.3801            64.0391
0.180       1.188      0.180             1.1267           20.7513           -26.9219
0.200       1.599      0.200             1.5333           19.7513           -73.0882
0.220       1.930      0.220             1.9138           18.3098           -71.0464
0.240       2.299      0.240             2.2667           17.0260           -57.3406
0.260       2.592      0.260             2.5933           16.2563           -19.6300
0.280       2.891      0.280             2.9217           16.1946            13.4605
0.300       3.190      0.300             3.2489           16.5674            23.8129
0.320       3.516      0.320             3.5828           16.7113            -9.4114
0.340       3.930      0.340             3.9097           15.6972           -92.0048
0.360       4.316      0.360             4.2007           13.1631          -159.4074
0.380       4.511      0.380             4.4337           10.1725          -141.6544
0.400       4.553      0.400             4.6138            8.0835           -67.2494
0.420       4.726      0.420             4.7639            7.0314           -37.9453
0.440       4.884      0.440             4.8971            6.2889           -36.3197
0.460       5.087      0.460             5.0151            5.4807           -44.4944

N.B.  DATA FOR SUBJECT 3, PITCH 1, TIME INTERVAL .02 SECONDS BETWEEN FRAMES
```

```
                    SEGMENTAL ANALYSIS PROGRAM-3 SEGMENTS

                    ANGULAR KINEMATICS OF THE LOWER ARM

         INPUT                                                   OUTPUT

    X           F          TIME       DISPLACEMENT       VELOCITY       ACCELERATION
  0.0        -0.823      0.0            -0.8339           7.1741          0.0
  0.020      -0.702      0.020          -0.6888           7.4041         23.0024
  0.040      -0.551      0.040          -0.5364           7.8267         19.2617
  0.060      -0.396      0.060          -0.3782           7.8809        -13.8455
  0.080      -0.204      0.080          -0.2280           6.9177        -82.4735
  0.100      -0.066      0.100          -0.1074           5.0732       -101.9807
  0.120      -0.020      0.120          -0.0220           3.6898        -36.3593
  0.140       0.043      0.140           0.0495           3.6679         34.1767
  0.160       0.119      0.160           0.1333           4.9814         92.1676
  0.180       0.253      0.180           0.2524           7.0705        121.7401
  0.200       0.417      0.200           0.4201           9.8048        151.6993
  0.220       0.636      0.220           0.6481          13.0741        175.2312
  0.240       0.907      0.240           0.9446          16.5670        174.0635
  0.260       1.336      0.260           1.3056          19.2792         97.1477
  0.280       1.726      0.280           1.7096          21.0771         62.6397
  0.300       2.178      0.300           2.1490          22.9172        101.3729
  0.320       2.624      0.320           2.6327          25.7165        178.5560
  0.340       3.094      0.340           3.1868          29.8673        238.5264
  0.360       3.734      0.360           3.8236          33.3698        109.7122
  0.380       4.500      0.380           4.4922          32.4521       -201.4714
  0.400       5.191      0.400           5.0812          25.4620       -497.5476
  0.420       5.628      0.420           5.4862          14.7932       -569.3242
  0.440       5.689      0.440           5.6827           5.5858       -351.4182
  0.460       5.685      0.460           5.7396           0.8735       -119.8129

N.B.  DATA FOR SUBJECT 3, PITCH 1, TIME INTERVAL .02 SECONDS BETWEEN FRAMES
```

```
                         SEGMENTAL ANALYSIS PROGRAM-3 SEGMENTS

                       ANGULAR KINEMATICS OF THE HAND SEGMENT

          INPUT                                               OUTPUT

   X           F          TIME        DISPLACEMENT       VELOCITY       ACCELERATION
0.0         -6.695       0.0            -0.6649          11.8160           0.0
0.020       -0.403       0.020          -0.4348          10.8886         -92.7390
0.040       -0.231       0.040          -0.2358           8.9996         -96.1641
0.060       -0.055       0.060          -0.0744           7.1754         -86.2522
0.080        0.012       0.080           0.0561           6.0876         -22.5262
0.100        0.165       0.100           0.1693           5.0299         -83.2495
0.120        0.305       0.120           0.2484           2.6387        -155.8679
0.140        0.330       0.140           0.2759           0.3989         -68.1116
0.160        0.188       0.160           0.2862           1.4387         172.0939
0.180        0.350       0.180           0.3469           4.4978         133.8141
0.200        0.493       0.200           0.4617           6.8922         105.6245
0.220        0.655       0.220           0.6246           9.5926         164.4144
0.240        0.741       0.240           0.8590          14.3273         309.0576
0.260        1.227       0.260           1.1948          18.6300         121.2023
0.280        1.606       0.280           1.5652          20.0878          24.5818
0.300        2.070       0.300           1.9893          20.1914         -14.2224
0.320        2.433       0.320           2.4030          21.8060         175.6788
0.340        2.867       0.340           2.8925          28.0666         450.3796
0.360        3.396       0.360           3.5575          39.1019         653.1543
0.380        4.177       0.380           4.4537          49.6996         406.6184
0.400        5.548       0.400           5.4604          47.5418        -622.3970
0.420        6.520       0.420           6.2346          27.2737       -1404.4023
0.440        6.846       0.440           6.5008          -0.5755       -1390.5200
0.460        6.061       0.460           6.2795         -18.1886        -380.7979

N.B.  DATA FOR SUBJECT 3, PITCH 1, TIME INTERVAL .02 SECONDS BETWEEN FRAMES
```

LINEAR KINEMATICS OF SHOULDER

X-COORDINATES OF SHOULDER

INPUT		OUTPUT			
X	F	TIME	DISPLACEMENT	VELOCITY	ACCELERATION
0.0	0.144	0.0	0.1293	0.8012	0.0
0.020	0.155	0.020	0.1454	0.8057	0.4560
0.040	0.165	0.040	0.1616	0.8225	1.2263
0.060	0.172	0.060	0.1784	0.8559	2.1166
0.080	0.190	0.080	0.1960	0.9051	2.8018
0.100	0.225	0.100	0.2147	0.9660	3.2886
0.120	0.237	0.120	0.2347	1.0398	4.0992
0.140	0.250	0.140	0.2564	1.1305	4.9809
0.160	0.272	0.160	0.2800	1.2370	5.6734
0.180	0.305	0.180	0.3059	1.3550	6.1315
0.200	0.327	0.200	0.3343	1.4819	6.5634
0.220	0.355	0.220	0.3653	1.6153	6.7775
0.240	0.395	0.240	0.3989	1.7499	6.6881
0.260	0.428	0.260	0.4352	1.8815	6.4891
0.280	0.453	0.280	0.4741	2.0070	6.0650
0.300	0.510	0.300	0.5154	2.1175	4.9899
0.320	0.560	0.320	0.5587	2.2047	3.7306
0.340	0.610	0.340	0.6034	2.2670	2.5058
0.360	0.665	0.360	0.6492	2.3070	1.4909
0.380	0.703	0.380	0.6955	2.3315	0.9664
0.400	0.752	0.400	0.7424	2.3481	0.6667
0.420	0.784	0.420	0.7895	2.3621	0.7169
0.440	0.822	0.440	0.8369	2.3749	0.5596
0.460	0.906	0.460	0.8845	2.3798	-0.0610

N.B. DATA FOR SUBJECT 3, PITCH 1, TIME INTERVAL .02 SECONDS BETWEEN FRAMES

```
                              LINEAR KINEMATICS OF SHOULDER

          INPUT                                                        OUTPUT

   X             F             TIME         DISPLACEMENT         VELOCITY        ACCELERATION

                                    Y-COORDINATES OF SHOULDER
 0.0           0.410         0.0              0.4149              0.6146             0.0
 0.020         0.422         0.020            0.4271              0.6046            -1.0015
 0.040         0.441         0.040            0.4389              0.5638            -3.0737
 0.060         0.453         0.060            0.4494              0.4866            -4.6522
 0.080         0.455         0.080            0.4582              0.3858            -5.4297
 0.100         0.452         0.100            0.4647              0.2620            -6.9499
 0.120         0.477         0.120            0.4683              0.0800           -11.2418
 0.140         0.474         0.140            0.4675             -0.1694           -13.6978
 0.160         0.466         0.160            0.4613             -0.4542           -14.7837
 0.180         0.456         0.180            0.4492             -0.7496           -14.7551
 0.200         0.441         0.200            0.4314             -1.0296           -13.2419
 0.220         0.416         0.220            0.4084             -1.2580            -9.5959
 0.240         0.388         0.240            0.3816             -1.4094            -5.5427
 0.260         0.355         0.260            0.3526             -1.4660            -0.1222
 0.280         0.332         0.280            0.3237             -1.4082             5.9063
 0.300         0.290         0.300            0.2972             -1.2125            13.6594
 0.320         0.264         0.320            0.2761             -0.8765            19.9354
 0.340         0.259         0.340            0.2628             -0.4417            23.5417
 0.360         0.246         0.360            0.2589              0.0574            26.3743
 0.380         0.253         0.380            0.2653              0.5856            26.4393
 0.400         0.253         0.400            0.2822              1.0894            23.9438
 0.420         0.311         0.420            0.3082              1.4819            15.3027
 0.440         0.355         0.440            0.3403              1.7076             7.2667
 0.460         0.387         0.460            0.3756              1.8049             2.4624

N.B.  DATA FOR SUBJECT 3, PITCH 1, TIME INTERVAL .02 SECONDS BETWEEN FRAMES
```

LINEAR VELOCITIES AND ACCELERATIONS OF SEGMENTAL ENDPOINTS

ELBOW KINEMATICS

FRAME	X-VELOCITY	Y-VELOCITY	X-ACCELERATION	Y-ACCELERATION
1	3.0714	1.4279	-10.4340	22.4440
2	3.0056	1.7833	-5.5875	25.7206
3	2.9890	2.2085	-5.8558	30.0059
4	2.9431	2.7420	-8.9302	38.4077
5	2.7709	3.4595	-18.8359	51.2133
6	2.2666	4.3632	-41.5839	60.4863
7	1.1401	5.2633	-77.5949	55.1927
8	-0.7961	5.6093	-111.9300	11.7059
9	-3.1587	4.6358	-102.6177	-63.1651
10	-4.8286	2.1926	-31.3455	-118.7717
11	-5.0314	-0.7849	46.1689	-113.5243
12	-4.0750	-3.2901	89.0978	-76.3240
13	-2.5623	-5.0113	106.5332	-37.0373
14	-0.8919	-6.0580	108.3192	-9.0758
15	0.8411	-6.6237	112.3640	15.1931
16	2.7032	-6.6483	115.9762	50.6332
17	4.5598	-5.8631	100.3840	98.9448
18	5.8659	-4.1675	46.8298	137.4560
19	6.1002	-2.0726	-17.0529	132.5507
20	5.5589	-0.3379	-40.5388	95.8472
21	5.0026	0.8268	-28.0611	66.5674
22	4.6794	1.6015	-23.0492	47.5603
23	4.4149	2.0888	-24.3580	32.8302
24	4.1063	2.3440	-26.9236	20.5914

N.B. DATA FOR SUBJECT 3, PITCH 1, TIME INTERVAL .02 SECONDS BETWEEN FRAMES

LINEAR VELOCITIES AND ACCELERATIONS OF SEGMENTAL ENDPOINTS

KINEMATICS OF THE ARM CENTER OF GRAVITY

FRAME	X-VELOCITY	Y-VELOCITY	X-ACCELERATION	Y-ACCELERATION
1	1.7910	0.9692	-10.4340	22.4440
2	1.7649	1.1185	-9.7860	23.4712
3	1.7671	1.2809	-12.1283	25.2440
4	1.7659	1.4699	-17.1005	29.5786
5	1.7186	1.7259	-27.8917	36.2944
6	1.5351	2.0501	-48.3600	39.1197
7	1.0061	2.3399	-78.1549	27.8785
8	0.2405	2.3501	-104.3898	-10.9098
9	-0.6795	1.7650	-94.8274	-72.1858
10	-1.3410	0.5332	-35.8701	-116.6169
11	-1.3574	-0.9229	32.5753	-113.0137
12	-0.8657	-2.1440	76.6449	-80.7711
13	-0.1302	-2.9798	98.3425	-43.8790
14	0.6723	-3.4681	106.4304	-12.2032
15	1.4987	-3.6821	112.9106	17.6360
16	2.3729	-3.5825	115.5013	55.0397
17	3.2315	-3.0507	101.1321	97.3609
18	3.8362	-2.0662	58.7267	125.1418
19	3.9608	-0.8713	[illegible].8164	118.0240
20	3.7387	0.1830	-15.1914	86.5941
21	3.5055	0.9749	-15.6255	65.3350
22	3.3724	1.5341	-15.9962	47.9242
23	3.2643	1.8738	-17.7132	34.0716
24	3.1320	2.0400	-19.0187	23.0598

N.B. DATA FOR SUBJECT 3, PITCH 1, TIME INTERVAL .02 SECONDS BETWEEN FRAMES

LINEAR VELOCITIES AND ACCELERATIONS OF SEGMENTAL ENDPOINTS

WRIST KINEMATICS

FRAME	X-VELOCITY	Y-VELOCITY	X-ACCELERATION	Y-ACCELERATION
1	4.5589	2.7778	-30.3619	55.1499
2	4.3236	3.3837	-26.5468	62.7047
3	4.1090	4.0922	-35.1281	66.8014
4	3.7579	4.7927	-48.1323	64.4208
5	3.2086	5.3463	-61.0389	50.9142
6	2.8189	5.7755	-73.9447	44.3676
7	1.1688	6.2962	-101.0498	49.3271
8	-0.6467	6.6351	-136.7384	18.1582
9	-3.3423	6.0044	-135.6580	-54.0694
10	-5.3229	4.1096	-68.9136	-123.3996
11	-6.1512	1.7217	11.9637	-135.0532
12	-6.2850	-0.3716	64.3369	-119.3794
13	-6.3206	-2.2926	105.0248	-113.1899
14	-6.1013	-4.6432	171.5854	-119.5749
15	-5.0037	-7.4405	246.2709	-93.4717
16	-2.6706	-10.1550	324.9287	-26.0801
17	1.0516	-12.1513	388.5164	82.3315
18	6.2438	-12.5274	424.2556	257.3501
19	11.9902	-9.3259	313.5154	508.8123
20	14.4262	-2.3223	-20.2248	576.3264
21	11.6525	3.3972	-244.5237	313.0352
22	7.6421	4.4962	-203.5836	49.2070
23	5.2966	3.3792	-98.8317	-18.7567
24	4.2323	2.5533	-46.5056	-4.4230

N.B. DATA FOR SUBJECT 3, PITCH 1, TIME INTERVAL .02 SECONDS BETWEEN FRAMES

LINEAR VELOCITIES AND ACCELERATIONS OF SEGMENTAL ENDPOINTS

KINEMATICS OF THE LOWER ARM CENTER OF GRAVITY

FRAME	X-VELOCITY	Y-VELOCITY	X-ACCELERATION	Y-ACCELERATION
1	3.7110	2.0083	-30.3619	55.1499
2	3.5724	2.4715	-28.8604	59.8707
3	3.4706	3.0185	-36.6942	64.1590
4	3.2934	3.6238	-47.3163	66.4744
5	2.9591	4.2708	-58.0642	63.7364
6	2.3321	4.9705	-72.2000	60.5500
7	1.1556	5.7074	-100.9223	55.1286
8	-0.8179	6.0504	-136.4698	12.7102
9	-3.2377	5.2243	-133.7026	-68.6485
10	-5.0411	3.0169	-64.0622	-142.2139
11	-5.5129	0.2929	21.8385	-157.1591
12	-5.0253	-2.0351	81.2201	-141.6752
13	-4.1785	-3.8423	127.5338	-129.4718
14	-2.1319	-5.4496	136.5461	-123.6380
15	-1.6721	-6.9749	259.3330	-91.6463
16	0.3926	-8.1562	338.4783	-17.2384
17	3.0514	-6.5670	402.4001	107.2186
18	6.0284	-7.7622	422.5364	295.3801
19	8.6329	-5.1915	302.4773	522.4050
20	9.3718	-1.1912	11.1538	569.3040
21	7.8621	1.9321	-170.4557	341.6648
22	5.9533	2.8462	-136.5913	112.7073
23	4.7949	2.6436	-67.1406	27.5181
24	4.1606	2.4340	-36.6151	11.9427

N.B. DATA FOR SUBJECT 3, PITCH 1, TIME INTERVAL .02 SECONDS BETWEEN FRAMES

LINEAR VELOCITIES AND ACCELERATIONS OF SEGMENTAL ENDPOINTS

KINEMATICS OF THE HAND CENTER OF GRAVITY

FRAME	X-VELOCITY	Y-VELOCITY	X-ACCELERATION	Y-ACCELERATION
1	4.8420	3.1389	-78.4235	35.4547
2	4.5017	3.7672	-79.8223	24.1914
3	4.1906	4.4320	-83.7516	0.8441
4	3.7786	5.0706	-89.8921	-23.9774
5	3.1953	5.5824	-98.6683	-42.6680
6	2.3860	5.9680	-105.9087	-65.5562
7	1.1436	6.3955	-117.1111	-104.0706
8	-0.8569	6.5500	-138.6359	-139.6273
9	-3.3561	6.0580	-146.4592	-134.1363
10	-5.3823	4.2739	-91.8036	-88.9217
11	-6.2704	1.9613	-7.6287	-29.6942
12	-6.5026	-0.0694	53.8147	1.7635
13	-6.7421	-1.9291	110.1857	0.7465
14	-6.7743	-4.3775	236.0337	14.8692
15	-5.7337	-7.4517	395.5867	89.7821
16	-3.3870	-10.4737	553.4573	219.5647
17	0.4916	-12.7775	697.6589	362.0027
18	5.9751	-13.5836	877.4316	555.6150
19	12.6836	-10.7151	882.4163	844.8206
20	16.2921	-2.8161	199.1048	1023.9058
21	13.5059	4.6530	-636.9829	522.8193
22	7.6935	5.5541	-431.9099	-44.6243
23	5.3034	3.3574	-85.3557	-154.2405
24	4.2304	1.8470	-45.9986	-138.1290

N.B. DATA FOR SUBJECT 3, PITCH 1, TIME INTERVAL .02 SECONDS BETWEEN FRAMES

LINEAR VELOCITIES AND ACCELERATIONS OF SEGMENTAL ENDPOINTS

FINGERTIP KINEMATICS

FRAME	X-VELOCITY	Y-VELOCITY	X-ACCELERATION	Y-ACCELERATION
1	5.5701	4.0675	-78.4235	35.4547
2	4.9597	4.7534	-83.7235	15.7919
3	4.4006	5.3059	-85.9952	-8.4935
4	3.8319	5.7852	-90.5323	-32.5671
5	3.1612	6.1693	-98.5421	-44.9140
6	2.3013	6.4631	-104.5077	-73.7509
7	1.0788	6.6509	-113.2839	-119.1584
8	-0.3618	6.6883	-136.8331	-146.1720
9	-1.3966	6.1958	-151.3118	-117.6496
10	-5.5350	4.6963	-96.3467	-76.3545
11	-6.5770	2.5775	-12.3278	-20.2506
12	-7.0630	0.7076	44.2131	15.0824
13	-7.8255	-0.9945	86.8161	20.9066
14	-8.5043	-3.6944	224.7754	19.3134
15	-7.7895	-7.4807	393.1321	89.7467
16	-5.2294	-11.2931	554.7551	220.1419
17	-0.9845	-14.3876	685.8469	349.0310
18	5.2842	-16.3001	866.3447	512.0261
19	14.1811	-14.2671	908.7664	785.1533
20	21.0901	-4.0558	237.3599	1013.5176
21	16.4862	7.6823	-682.5452	480.5425
22	7.8257	8.2746	-438.7175	-184.7083
23	5.3159	3.3012	-55.5889	-288.8528
24	4.2243	0.0306	-46.1256	-176.1568

N.B. DATA FOR SUBJECT 5, PITCH 1, TIME INTERVAL .02 SECONDS BETWEEN FRAMES

KINETICS OF THE UPPER EXTREMITY

FORCES AND MOMENTS AT THE WRIST JOINT

FRAME	X-JOINT FORCES	Y-JOINT FORCES	MOMENT AT THE JOINT
1	-43.63875	25.30521	1.82386
2	-44.62066	14.31367	1.07460
3	-46.51712	0.73816	0.28725
4	-50.24969	-12.71896	-0.49591
5	-55.15556	-19.62090	-0.91969
6	-59.20296	-35.74072	-1.89881
7	-65.46510	-61.12349	-3.19413
8	-77.52541	-76.22411	-3.78556
9	-81.87070	-69.28009	-2.84753
10	-51.31818	-37.19614	-1.80591
11	-4.26485	-5.63407	-0.09495
12	30.08241	13.91708	1.40442
13	61.59380	17.17282	2.77844
14	131.94288	16.26218	5.20687
15	221.13295	55.65440	8.59811
16	309.38257	128.54536	8.92486
17	339.59121	200.59436	4.73942
18	450.43413	291.70825	-5.50912
19	493.27051	444.38647	-22.40266
20	119.74055	572.04199	-9.14160
21	-356.07324	274.10889	16.30707
22	-241.43764	-97.76587	-5.75280
23	-47.71384	-155.98267	-8.68944
24	-25.71321	-92.98561	-4.26281

N.B. DATA FOR SUBJECT 2, PITCH 1, TIME INTERVAL .02 SECONDS BETWEEN FRAMES

KINETICS OF THE UPPER EXTREMITY

FORCES AND MOMENTS AT THE ELBOW JOINT

FRAME	X-JOINT FORCES	Y-JOINT FORCES	MOMENT AT THE JOINT
1	-80.18193	103.06689	6.15221
2	-79.19049	97.72617	6.11320
3	-90.74600	89.28384	6.96880
4	-106.88731	78.59816	7.89450
5	-124.65842	68.41893	7.23761
6	-145.62633	48.48491	8.98144
7	-186.26910	16.61278	14.01700
8	-240.87967	-49.26262	16.74594
9	-241.91264	-130.70529	11.59878
10	-128.00064	-195.67868	5.70176
11	21.47625	-182.20609	2.16863
12	127.30284	-143.92073	4.83716
13	214.25174	-126.05751	15.37870
14	355.24072	-119.96603	40.47067
15	531.55420	-42.29877	72.76207
16	714.54077	119.65842	101.98312
17	871.65382	346.68213	108.47112
18	996.25977	657.02539	71.86400
19	855.33569	1081.45215	-11.96455
20	124.09167	1265.24585	-6.09233
21	-560.10864	694.82861	77.50131
22	-407.33130	48.89209	57.00638
23	-128.08113	-111.29616	31.97737
24	-64.54147	-66.94290	20.74944

N.B. DATA FOR SUBJECT 3, PITCH 1, TIME INTERVAL .02 SECONDS BETWEEN FRAMES

KINETICS OF THE UPPER EXTREMITY

FORCES AND MOMENTS AT THE SHOULDER JOINT

FRAME	X-JOINT FORCES	Y-JOINT FORCES	MOMENT AT THE JOINT
1	-103.44977	153.11690	48.11252
2	-101.01329	150.06691	51.26271
3	-117.79210	145.57799	57.55946
4	-145.02133	144.55832	62.99602
5	-186.85693	149.35532	64.53595
6	-253.46907	135.72173	58.05267
7	-360.55420	78.78180	33.42957
8	-473.66870	-73.59154	-34.92737
9	-455.37769	-291.67944	-109.23663
10	-207.49104	-455.73828	-87.24393
11	94.51912	-434.22656	14.60844
12	296.22070	-324.04028	90.69180
13	433.55542	-223.90775	128.29601
14	592.58032	-147.17915	155.54066
15	783.34448	-2.46594	127.32693
16	972.10640	242.39699	16.45152
17	1097.18823	557.79666	-158.34117
18	1127.22021	936.09131	-356.47876
19	874.99609	1344.64551	-457.31299
20	90.21495	1462.81055	-166.56305
21	-594.95337	840.52563	240.31522
22	-443.00269	355.76312	197.16542
23	-167.58144	-35.31642	73.57892
24	-111.55314	-15.51947	43.12593

N.B. DATA FOR SUBJECT 3, PITCH 1, TIME INTERVAL .02 SECONDS BETWEEN FRAMES

```
                              SEGMENTAL ANALYSIS PROGRAM-3 SEGMENTS
                               ANGULAR KINEMATICS OF THE UPPER ARM

                                                                   OUTPUT
           INPUT

     X           F            TIME          DISPLACEMENT        VELOCITY         ACCELERATION
   0.0         -2.151         0.0             -2.1732            6.6602             0.0
   0.020       -2.022         0.020           -2.0380            6.9585            29.8295
   0.040       -1.917         0.040           -1.8895            8.0713            81.4518
   0.060       -1.739         0.060           -1.7108            9.8405            95.4690
   0.080       -1.491         0.080           -1.4965           11.5102            71.4996
   0.100       -1.234         0.100           -1.2531           12.7802            55.5056
   0.120       -0.993         0.120           -0.9857           13.9901            65.4779
   0.140       -0.682         0.140           -0.6928           15.3051            66.0284
   0.160       -0.376         0.160           -0.3725           16.7753            80.9886
   0.180       -0.031         0.180           -0.0200           18.5016            91.6456
   0.200        0.328         0.200            0.3681           20.2952            87.7169
   0.220        0.600         0.220            0.7875           21.4552            28.2820
   0.240        1.233         0.240            1.2194           21.5914           -14.6685
   0.260        1.678         0.260            1.6467           21.0532           -39.1471
   0.280        2.109         0.280            2.0612           20.4563           -20.5428
   0.300        2.425         0.300            2.4718           20.8878            63.6898
   0.320        2.814         0.320            2.9036           22.3617            83.7031
   0.340        3.283         0.340            3.3607           23.0047           -19.4009
   0.360        3.904         0.360            3.8030           20.5172          -229.3529
   0.380        4.305         0.380            4.1627           15.2151          -300.8684
   0.400        4.428         0.400            4.4150           10.4363          -177.0016
   0.420        4.514         0.420            4.5979            8.3181           -34.8228
   0.440        4.743         0.440            4.7591            7.8932            -7.6614
   0.460        4.913         0.460            4.9158            7.7953            -2.1280

N.B.  DATA FOR SUBJECT 4, PITCH 1, TIME INTERVAL .02 SECONDS BETWEEN FRAMES
```

```
                    SEGMENTAL ANALYSIS PROGRAM-3 SEGMENTS

                      ANGULAR KINEMATICS OF THE LOWER ARM

          INPUT                                               OUTPUT
   X             F           TIME        DISPLACEMENT      VELOCITY      ACCELERATION
  0.0         -2.124         0.0          -2.1502           6.5763          0.0
  0.020       -2.022         0.020        -2.0122           7.5419         96.5592
  0.040       -1.876         0.040        -1.9380          10.0855        157.7966
  0.060       -1.588         0.060        -1.6098          12.4803         81.6858
  0.080       -1.362         0.080        -1.3437          14.1337         83.6552
  0.100       -1.044         0.100        -1.0486          15.1681         19.7903
  0.120       -0.732         0.120        -0.7444          15.0952        -27.0866
  0.140       -0.456         0.140        -0.4481          14.5208        -30.3543
  0.160       -0.161         0.160        -0.1659          13.5992        -61.8093
  0.180        0.125         0.180         0.0929          12.2336        -74.7440
  0.200        0.317         0.200         0.3296          11.7822         29.6033
  0.220        0.563         0.220         0.5750          12.9460         86.7712
  0.240        0.859         0.240         0.8570          15.5435        172.9838
  0.260        1.132         0.260         1.2087          19.9454        267.2007
  0.280        1.644         0.280         1.6487          23.4385         82.1136
  0.300        2.195         0.300         2.1206          23.0744       -118.5194
  0.320        2.618         0.320         2.5630          21.4060        -48.3302
  0.340        2.972         0.340         2.9995          23.1464        222.3792
  0.360        3.417         0.360         3.5182          29.2890        391.8818
  0.380        4.071         0.380         4.1692          35.1466        193.8770
  0.400        4.961         0.400         4.8740          33.4848       -360.0627
  0.420        5.549         0.420         5.4558          23.9024       -598.1655
  0.440        5.864         0.440         5.8208          12.9283       -499.2612
  0.460        5.992         0.460         5.9966           5.5160       -241.9638

N.B.  DATA FOR SUBJECT 4, PITCH 1, TIME INTERVAL .02 SECONDS BETWEEN FRAMES
```

```
                    SEGMENTAL ANALYSIS PROGRAM-3 SEGMENTS

                    ANGULAR KINEMATICS OF THE HAND SEGMENT

    INPUT                                                     OUTPUT

  X           F           TIME        DISPLACEMENT       VELOCITY       ACCELERATION
0.0         -2.106      0.0           -2.1602            3.6506           0.0
0.020       -2.128      0.020         -2.0713            6.0373         238.6722
0.040       -1.928      0.040         -1.9037           10.6806         225.6500
0.060       -1.644      0.060         -1.6528           14.0129         107.5775
0.080       -1.369      0.080         -1.3562           15.3918          30.3084
0.100       -0.992      0.100         -1.0512           14.6678        -102.7035
0.120       -0.792      0.120         -0.7699           13.8899          24.9156
0.140       -0.526      0.140         -0.4851           14.6796          54.0559
0.160       -0.144      0.160         -0.1907           14.2647         -95.5472
0.180        0.038      0.180          0.0793           12.9320         -37.7288
0.200        0.403      0.200          0.3221           10.9314        -162.3276
0.220        0.523      0.220          0.5238           10.0078          69.9676
0.240        0.665      0.240          0.7531           13.6840         297.6594
0.260        1.151      0.260          1.0757           18.0441         138.3376
0.280        1.338      0.280          1.4757           22.5232         309.5754
0.300        2.026      0.300          1.9590           24.3667        -125.2225
0.320        2.549      0.320          2.4120           20.4563        -265.8131
0.340        2.823      0.340          2.7989           19.7911         199.2978
0.360        3.130      0.360          3.2727           29.4842         770.0103
0.380        3.674      0.380          4.0126           44.3226         713.8262
0.400        5.287      0.400          4.9386           43.1183        -834.2559
0.420        5.737      0.420          5.6332           26.2962        -347.9487
0.440        5.871      0.440          6.0192           13.7772        -403.9565
0.460        6.387      0.460          6.1999            3.5981        -613.9399

N.B.  DATA FOR SUBJECT 4, PITCH 1, TIME INTERVAL .02 SECONDS BETWEEN FRAMES
```

LINEAR KINEMATICS OF SHOULDER

INPUT			OUTPUT		
X	F	TIME	DISPLACEMENT	VELOCITY	ACCELERATION
			X-COORDINATES OF SHOULDER		
0.0	0.735	0.0	0.7339	2.2359	0.0
0.020	0.776	0.020	0.7802	2.4729	23.6982
0.040	0.834	0.040	0.8308	2.4076	-30.2296
0.060	0.877	0.060	0.8734	1.8782	-22.7066
0.080	0.914	0.080	0.9120	2.2515	60.0364
0.100	0.951	0.100	0.9776	4.7459	189.3961
0.120	1.110	0.120	1.0842	4.5970	-204.2789
0.140	1.141	0.140	1.1431	1.6691	-86.5124
0.160	1.165	0.160	1.1644	0.6788	-14.5112
0.180	1.172	0.180	1.1813	1.3306	79.6841
0.200	1.225	0.200	1.2179	1.9309	-19.6520
0.220	1.254	0.220	1.2558	2.1217	38.7288
0.240	1.310	0.240	1.3075	3.1134	60.4463
0.260	1.371	0.260	1.3861	4.9625	124.4603
0.280	1.514	0.280	1.4950	5.1707	-103.6367
0.300	1.575	0.300	1.5870	4.4874	35.3022
0.320	1.684	0.320	1.6774	4.2409	-59.9474
0.340	1.752	0.340	1.7531	3.4724	-16.9046
0.360	1.820	0.360	1.8210	3.3978	9.4428
0.380	1.888	0.380	1.8917	3.7181	22.5854
0.400	1.973	0.400	1.9668	3.6085	-33.5449
0.420	2.034	0.420	2.0362	3.5246	25.1620
0.440	2.106	0.440	2.1133	4.2579	48.1576
0.460	2.209	0.460	2.2006	4.1082	-63.1164

N.B. DATA FOR SUBJECT 4, PITCH 1, TIME INTERVAL .02 SECONDS BETWEEN FRAMES

```
                         LINEAR KINEMATICS OF SHOULDER


          INPUT                                                 OUTPUT

    X              F              TIME        DISPLACEMENT       VELOCITY        ACCELERATION

                                      Y-COORDINATES OF SHOULDER
  0.0            0.581          0.0             0.5799           0.2505             0.0
  0.020          0.587          0.020           0.5856           0.3495             9.8962
  0.040          0.591          0.040           0.5963           0.8119            36.3470
  0.060          0.620          0.060           0.6171           1.1354            -3.9976
  0.080          0.636          0.080           0.6386           0.9871           -10.8285
  0.100          0.663          0.100           0.6538           0.4149           -46.3938
  0.120          0.651          0.120           0.6582           0.2885            33.7513
  0.140          0.669          0.140           0.6698           0.8280            20.2010
  0.160          0.692          0.160           0.6890           1.0246            -0.5415
  0.180          0.698          0.180           0.7104           1.1721            15.2862
  0.200          0.748          0.200           0.7276           0.0741          -125.0877
  0.220          0.702          0.220           0.7114          -1.3267           -14.9869
  0.240          0.682          0.240           0.6815          -1.6782           -20.1640
  0.260          0.653          0.260           0.6436          -2.1202           -24.0388
  0.280          0.583          0.280           0.6038          -1.5013            85.9318
  0.300          0.601          0.300           0.5806          -1.3297           -68.7662
  0.320          0.537          0.320           0.5473          -1.6514            36.5912
  0.340          0.525          0.340           0.5203          -1.1082            17.7258
  0.360          0.502          0.360           0.5044          -0.3413            58.9684
  0.380          0.509          0.380           0.5104           0.9932            74.4849
  0.400          0.548          0.400           0.5449           2.4434            70.5310
  0.420          0.594          0.420           0.6100           4.1604           101.1703
  0.440          0.712          0.440           0.7020           4.4714           -70.0742
  0.460          0.767          0.460           0.7748           2.6783          -109.2367

N.B.  DATA FOR SUBJECT 4, PITCH 1, TIME INTERVAL .02 SECONDS BETWEEN FRAMES
```

LINEAR VELOCITIES AND ACCELERATIONS OF SEGMENTAL ENDPOINTS

ELBOW KINEMATICS

FRAME	X-VELOCITY	Y-VELOCITY	X-ACCELERATION	Y-ACCELERATION
1	4.6780	-1.4289	9.5168	31.1562
2	5.2375	-1.0453	42.8230	40.3623
3	5.8185	-0.3134	6.7208	71.9535
4	6.2144	0.5243	14.2020	51.2261
5	7.3594	1.3673	76.0277	76.2419
6	10.1464	2.1917	184.8498	91.0212
7	9.7870	3.7268	-232.1261	186.7641
8	6.0389	6.0688	-160.6306	135.2371
9	3.3954	7.9778	-135.2258	89.9860
10	1.4956	9.4036	-93.4808	83.7316
11	-1.3166	8.5006	-206.2179	-115.4295
12	-4.6439	5.4099	-86.2610	-105.7434
13	-5.9077	1.6286	31.4107	-149.9662
14	-4.3792	-2.8307	201.4257	-114.9139
15	-2.8595	-5.7885	22.8389	31.7416
16	-1.2831	-8.6166	197.6883	-117.7869
17	1.8954	-11.3220	184.4509	42.7763
18	5.6979	-11.1005	236.5826	157.2324
19	9.0055	-7.5464	101.5870	324.2778
20	9.4913	-2.5441	-52.8660	288.8442
21	8.0489	1.0828	-120.1543	177.6083
22	7.2019	3.7374	-21.3203	162.8471
23	7.7665	4.6352	8.1650	-8.9301
24	7.5057	3.3789	-90.3833	-50.9192

N.B. DATA FOR SUBJECT 4, PITCH 1, TIME INTERVAL .02 SECONDS BETWEEN FRAMES

LINEAR VELOCITIES AND ACCELERATIONS OF SEGMENTAL ENDPOINTS

KINEMATICS OF THE ARM CENTER OF GRAVITY

FRAME	X-VELOCITY	Y-VELOCITY	X-ACCELERATION	Y-ACCELERATION
1	3.3006	-0.4817	9.5168	31.1562
2	3.6783	-0.2586	36.1386	43.7344
3	3.8947	0.3213	-12.6928	78.3582
4	3.7688	0.8690	-9.5243	54.5700
5	4.4786	1.1529	58.1323	74.9099
6	7.1014	1.1896	171.6163	86.6691
7	6.8598	1.7876	-245.8261	177.6880
8	3.5856	3.1130	-171.2144	122.4853
9	1.8633	4.0562	-142.6227	71.0532
10	1.4026	4.7610	-93.9417	60.7350
11	0.5141	3.7480	-198.2968	-135.9703
12	-0.8281	1.6105	-81.2310	-110.7518
13	-0.8198	-0.2364	27.9541	-148.6992
14	0.8895	-2.4300	191.6288	-115.6590
15	1.6695	-3.3705	18.2906	-29.3134
16	1.9714	-4.5068	207.6119	-105.2554
17	3.2183	-5.8678	189.4028	63.1921
18	4.4428	-5.4649	237.6412	152.4796
19	5.8428	-3.4827	136.9419	278.8518
20	6.2352	-0.5491	11.5206	249.3930
21	5.5445	1.8502	-77.6798	164.5931
22	5.1279	3.9760	-12.6378	161.8483
23	5.7877	4.5428	10.0857	-8.8404
24	5.5895	2.9837	-89.8602	-50.8113

N.B. DATA FOR SUBJECT 4, PITCH 1, TIME INTERVAL .02 SECONDS BETWEEN FRAMES

LINEAR VELOCITIES AND ACCELERATIONS OF SEGMENTAL ENDPOINTS

WRIST KINEMATICS

FRAME	X-VELOCITY	Y-VELOCITY	X-ACCELERATION	Y-ACCELERATION
1	6.3014	-2.4911	25.8989	72.5958
2	7.2491	-1.9958	83.6294	82.8649
3	8.6881	-1.0989	62.7017	147.2872
4	9.8933	0.3808	33.5290	173.7577
5	11.4219	2.3060	67.4799	243.2313
6	14.0266	4.4237	122.8111	306.6902
7	12.8040	7.0021	-343.2375	374.1658
8	7.6949	9.9295	-308.6948	241.8062
9	4.0577	11.9345	-300.5349	127.1840
10	1.1608	12.9970	-250.4356	75.9782
11	-2.4435	11.7893	-347.9480	-135.9569
12	-6.7208	8.6150	-211.7099	-171.2684
13	-9.3736	4.6307	-79.1394	-262.2544
14	-9.8816	-0.7466	142.6027	-284.0862
15	-9.7529	-6.3269	146.9811	-198.7375
16	-7.0871	-12.1731	508.3867	-263.0496
17	-1.5577	-16.6069	547.7776	21.3683
18	4.7311	-17.8599	640.6851	201.7996
19	12.1833	-15.5810	600.4585	573.6125
20	18.3671	-7.9033	273.8699	904.8223
21	17.7982	2.6718	-314.4548	756.4907
22	12.3929	8.5095	-354.6243	339.6431
23	9.4679	6.0486	-161.5916	-18.3414
24	7.9656	4.9398	-137.8049	-75.4506

N.B. DATA FOR SUBJECT 4, PITCH 1, TIME INTERVAL .02 SECONDS BETWEEN FRAMES

LINEAR VELOCITIES AND ACCELERATIONS OF SEGMENTAL ENDPOINTS

KINEMATICS OF THE LOWER ARM CENTER OF GRAVITY

FRAME	X-VELOCITY	Y-VELOCITY	X-ACCELERATION	Y-ACCELERATION
1	5.3760	-1.8856	25.8989	72.5958
2	6.1025	-1.4540	68.9494	89.8015
3	7.0524	-0.6511	37.1097	154.2926
4	7.7963	0.4626	19.8040	174.2932
5	9.1063	1.7710	53.7744	240.0644
6	11.8160	3.1514	119.9269	305.0303
7	11.0643	5.1352	-340.1519	377.5159
8	6.8370	7.7289	-306.4834	246.4064
9	3.6802	9.6792	-298.8191	137.4346
10	1.3517	10.9488	-251.6015	88.4922
11	-1.8023	9.9147	-346.3369	-140.6668
12	-5.5370	6.7881	-203.7755	-183.5130
13	-7.3981	2.9195	-57.1532	-281.2983
14	-6.7452	-1.9345	184.6195	-300.0005
15	-5.8237	-6.0200	160.7465	-197.6625
16	-3.7768	-10.1459	491.3943	-273.4622
17	0.4105	-13.5954	543.3337	14.5642
18	5.2822	-14.0070	645.9797	238.8160
19	10.3719	-11.0013	576.2229	634.8887
20	13.3079	-4.8486	245.9621	921.6729
21	12.2411	1.7661	-254.6988	766.2305
22	9.4340	5.7894	-280.5779	407.7148
23	8.4981	6.1030	-124.1411	56.7931
24	7.7034	4.0501	-126.3056	-36.4232

N.B. DATA FOR SUBJECT 4, PITCH 1, TIME INTERVAL .02 SECONDS BETWEEN FRAMES

LINEAR VELOCITIES AND ACCELERATIONS OF SEGMENTAL ENDPOINTS

FINGERTIP KINEMATICS

FRAME	X-VELOCITY	Y-VELOCITY	X-ACCELERATION	Y-ACCELERATION
1	6.7450	-2.7878	36.0761	50.5225
2	8.0235	-2.4193	128.8493	115.3250
3	10.1639	-1.6092	111.0673	160.4772
4	11.9351	0.2129	46.2209	199.4853
5	13.6205	2.7852	28.9406	278.0669
6	15.8880	5.4885	29.2741	348.3962
7	14.2174	8.4602	-458.2129	-143.1430
8	8.6957	11.8280	-478.6409	-171.1185
9	4.4530	13.9822	-502.6345	-250.7296
10	1.0110	14.8817	-442.4480	-242.8602
11	-2.9495	13.3052	-485.8794	-402.7017
12	-7.4525	9.8819	-315.7224	-277.4353
13	-10.7419	6.0903	-192.2417	-194.3820
14	-12.2029	0.5068	115.6613	-67.9772
15	-13.0309	-6.0140	237.3614	-142.2164
16	-10.3644	-13.5217	854.8118	262.2844
17	-3.5513	-18.6383	959.0449	504.0994
18	3.7589	-20.5851	1038.2976	687.6350
19	12.7467	-19.8546	1200.5708	864.6750
20	23.3241	-12.0767	888.9778	1240.4426
21	23.9415	4.0858	-609.4888	690.5027
22	14.7194	11.5701	-733.8955	-66.2537
23	9.9936	9.9930	-314.6790	-80.9207
24	8.0093	5.4640	-164.9308	-198.4336

N.B. DATA FOR SUBJECT 4, PITCH 1, TIME INTERVAL .02 SECONDS BETWEEN FRAMES

LINEAR VELOCITIES AND ACCELERATIONS OF SEGMENTAL ENDPOINTS

KINEMATICS OF THE HAND CENTER OF GRAVITY

FRAME	X-VELOCITY	Y-VELOCITY	X-ACCELERATION	Y-ACCELERATION
1	6.4256	-2.5742	36.0761	50.5225
2	7.4659	-2.1144	106.8076	127.3814
3	9.1013	-1.2416	88.6186	168.2395
4	10.4650	0.3338	34.9349	200.4133
5	12.0375	2.4402	25.8233	277.3877
6	14.5478	4.7218	38.6581	353.7644
7	13.1998	7.4103	-460.0383	-145.0261
8	8.1751	10.4611	-481.2944	-176.1521
9	4.1684	12.5078	-500.7280	-240.8543
10	1.1189	13.5247	-442.7627	-238.9012
11	-2.5852	12.2137	-491.2891	-386.4932
12	-6.9257	8.9697	-312.0388	-283.8130
13	-9.7567	5.0394	-170.8131	-217.2415
14	-10.5316	-0.3956	128.4746	-74.8960
15	-10.6707	-6.2393	269.8210	-145.3121
16	-8.0103	-12.5507	842.6113	257.2942
17	-2.1159	-17.2332	940.3931	483.2417
18	4.4569	-18.6229	1045.3464	707.3943
19	12.3411	-16.7776	1169.9771	945.0339
20	19.7550	-9.0719	831.4968	1288.8367
21	19.5183	3.0677	-523.9092	710.2004
22	13.0443	9.3665	-679.8801	4.8054
23	9.6151	8.5930	-303.5818	-39.8722
24	7.9778	5.0865	-159.5552	-134.0316

N.B. DATA FOR SUBJECT 4, PITCH 1, TIME INTERVAL .02 SECONDS BETWEEN FRAMES

KINETICS OF THE UPPER EXTREMITY

FORCES AND MOMENTS AT THE WRIST JOINT

FRAME	X-JOINT FORCES	Y-JOINT FORCES	MOMENT AT THE JOINT
1	27.59819	46.15744	-1.98948
2	81.70782	95.73132	-4.19215
3	67.79320	130.27275	-3.77660
4	26.72519	160.11397	-1.34668
5	19.75484	220.22887	1.20869
6	29.57347	274.03052	4.25121
7	-351.92920	-101.99664	7.09458
8	-366.19019	-123.39795	2.70116
9	-383.05688	-184.30043	-4.68481
10	-338.71338	-178.28032	-8.47246
11	-375.83594	-300.55884	-16.96515
12	-238.70969	-204.73027	-11.96204
13	-130.67200	-141.19447	-7.09832
14	98.26307	-44.49483	3.03584
15	206.41309	-101.28784	8.82561
16	644.59741	208.15527	20.87061
17	719.40063	393.14355	6.94029
18	799.68994	533.54834	-9.05239
19	910.33228	668.98389	-30.01141
20	636.09497	956.44604	-43.27295
21	-400.79028	535.74194	18.73053
22	-520.10815	-43.17632	9.26424
23	-232.24005	-54.39662	-0.72288
24	-122.05969	-144.29399	-7.07310

N.B. DATA FOR SUBJECT 4, PITCH 1, TIME INTERVAL .02 SECONDS BETWEEN FRAMES

KINETICS OF THE UPPER EXTREMITY

FORCES AND MOMENTS AT THE ELBOW JOINT

FRAME	X-JOINT FORCES	Y-JOINT FORCES	MOMENT AT THE JOINT
1	71.36731	185.42992	-1.34712
2	198.23219	264.08130	-12.54917
3	130.50851	407.61279	-10.67876
4	60.19386	471.25488	-6.22329
5	110.63362	642.52295	-17.90781
6	232.24989	806.11694	-43.35260
7	-926.78564	552.59033	99.17929
8	-666.14697	309.61401	82.13716
9	-888.06079	64.54955	66.71606
10	-763.91968	-12.14287	33.56236
11	-961.14502	-521.69995	31.46428
12	-583.08984	-498.28125	1.66054
13	-227.26093	-600.00269	-6.50873
14	410.28979	-534.90967	38.59314
15	478.07446	-418.75146	68.37207
16	1475.05347	-237.40996	213.40779
17	1637.63428	434.34229	219.40523
18	1691.39526	953.73267	183.31975
19	1884.14868	1758.53076	60.30132
20	1051.77075	2530.65820	-55.31744
21	-831.23096	1847.25635	104.88644
22	-994.28442	662.44702	122.34450
23	-442.03833	58.16927	37.11214
24	-335.51587	-189.26353	40.49915

N.B. DATA FOR SUBJECT 4, PITCH 1, TIME INTERVAL .02 SECONDS BETWEEN FRAMES

KINETICS OF THE UPPER EXTREMITY

FORCES AND MOMENTS AT THE SHOULDER JOINT

FRAME	X-JOINT FORCES	Y-JOINT FORCES	MOMENT AT THE JOINT
1	99.44191	277.34058	-88.86542
2	304.64155	393.09766	-172.74065
3	93.06477	638.76929	-126.42302
4	32.09715	632.23608	-57.00288
5	282.12376	863.50708	-72.80551
6	738.51782	1061.79053	-104.96469
7	-1651.97241	1076.77002	754.99097
8	-1391.22949	670.94556	559.28174
9	-1308.79761	274.15625	308.23560
10	-1041.04761	167.02536	74.61775
11	-1546.12036	-922.81226	-448.83472
12	-822.72119	-824.99902	-415.15942
13	-144.79643	-1038.66504	-208.23524
14	975.59473	-876.10352	351.45313
15	532.03174	-332.27686	344.28394
16	2067.50854	-547.91309	827.38086
17	2196.37231	620.75879	197.23097
18	2592.43652	1403.54736	-529.47974
19	2288.12720	2581.14331	-1255.85010
20	1085.75635	3266.36743	-1135.46924
21	-1060.38623	2332.80566	225.26204
22	-1031.56567	1139.89917	523.36206
23	-412.28540	32.09003	228.49144
24	-600.60327	-339.15674	214.12585

N.B. DATA FOR SUBJECT 4, PITCH 1, TIME INTERVAL .02 SECONDS BETWEEN FRAMES

APPENDIX H

Raw Data for Three Dimensional Analysis

RAW DATA FOR SUBJECT 1.

```
***************************************
*     CALCULATED X,Y,Z CCORDINATES    *
* THEIR STANDARD ERROR OF ESTIMATE    *
*     AND PROBABILITY FACTOR          *
***************************************


*********************************************************************************************************************
*      **                *                *                **                *                *                **                *
* NUM  **       X        *       Y        *       Z        *       SX        *       SY       *       SZ       *  PROBA.        *
*      **                *                *                **                *                *                **                *
*********************************************************************************************************************
*      **                *                *                **                *                *                **                *
*    1 ** 0.43594E+02 * 0.46802E+01 * 0.16374E+02 ** 0.73749E+01 * 0.10135E+01 * 0.32079E+01 **-0.0            *
*    2 ** 0.25816E+02 * 0.14291E+02 * 0.24207E+02 ** 0.17505E+01 * 0.12590E+01 * 0.25114E+01 ** 0.95687E+00 *
*    3 ** 0.16188E+02 * 0.10969E+02 * 0.31022E+02 ** 0.21444E+01 * 0.20059E+01 * 0.22521E+01 ** 0.86032E+00 *
*    4 ** 0.17805E+02 * 0.58067E+02 * 0.13549E+02 ** 0.23457E+01 * 0.40033E+01 * 0.26044E+01 ** 0.97717E+00 *
*    5 ** 0.26049E+02 * 0.56177E+01 * 0.12435E+02 ** 0.66036E+01 * 0.75240E+00 * 0.20756E+01 ** 0.15757E+00 *
*    6 ** 0.24049E+02 *-0.22028E+00 * 0.21148E+02 ** 0.11038E+02 * 0.76541E+00 * 0.41757E+01 ** 0.73686E+00 *
*    7 ** 0.20552E+02 * 0.11195E+02 * 0.25201E+02 ** 0.33567E+01 * 0.10130E+01 * 0.23743E+01 ** 0.97441E+00 *
*    8 ** 0.17449E+02 * 0.28903E+02 * 0.30240E+02 ** 0.22360E+01 * 0.19270E+01 * 0.22679E+01 ** 0.93801E+00 *
*    9 ** 0.19416E+02 * 0.59856E+02 * 0.32379E+02 ** 0.24636E+01 * 0.42085E+01 * 0.26188E+01 ** 0.81132E+00 *
*   10 ** 0.37720E+02 * 0.83449E+01 * 0.15681E+02 ** 0.59591E+01 * 0.10726E+01 * 0.20298E+01 ** 0.16058E-01 *

 FIT IS STOPPED AFTER TOO MANY CONSECUTIVE DIVERGENCES. = 11
*   11 ** 0.43833E+02 * 0.25826E+01 * 0.18130E+02 ** 0.93802E+01 * 0.92922E+00 * 0.41014E+01 ** 0.55538E-01 *
*   12 ** 0.18984E+02 * 0.11215E+02 * 0.29475E+02 ** 0.12338E+01 * 0.10049E+01 * 0.25704E+01 ** 0.85592E+00 *
*   13 ** 0.18255E+02 * 0.30453E+02 * 0.32000E+02 ** 0.23924E+01 * 0.20556E+01 * 0.24225E+01 ** 0.95183E+00 *
*   14 ** 0.20187E+02 * 0.59598E+02 * 0.31069E+02 ** 0.24961E+01 * 0.[illegible]1048E+01 * 0.25644E+01 ** 0.97544E+00 *
*   15 ** 0.28983E+02 * 0.55924E+01 * 0.17594E+02 ** 0.73531E+01 * 0.91148E+00 * 0.34075E+01 ** 0.24402E+00 *
*   16 ** 0.29527E+02 *-0.30174E+01 * 0.21709E+02 ** 0.11105E+02 * 0.80591E+00 * 0.46221E+01 ** 0.76380E+00 *
*   17 ** 0.11855E+02 * 0.64802E+01 * 0.30762E+02 ** 0.31984E+01 * 0.80225E+00 * 0.23824E+01 ** 0.65401E+00 *
*   18 ** 0.17635E+02 * 0.24040E+02 * 0.32800E+02 ** 0.22979E+01 * 0.19489E+01 * 0.24294E+01 ** 0.33057E+00 *
*   19 ** 0.20271E+02 * 0.61534E+02 * 0.32267E+02 ** 0.25397E+01 * 0.44795E+01 * 0.26659E+01 ** 0.58065E+00 *
*   20 ** 0.37653E+00 * 0.87456E+00 * 0.28413E+02 ** 0.64903E+01 * 0.64901E+00 * 0.27133E+01 ** 0.49658E+00 *
*   21 ** 0.28477E+02 *-0.34792E+01 * 0.22020E+02 ** 0.12247E+02 * 0.82648E+00 * 0.52991E+01 ** 0.41513E+00 *
*   22 ** 0.12555E+02 * 0.71467E+01 * 0.32679E+02 ** 0.32366E+01 * 0.82792E+00 * 0.25320E+01 ** 0.73771E+00 *
*   23 ** 0.19667E+02 * 0.30365E+02 * 0.32435E+02 ** 0.24110E+01 * 0.20853E+01 * 0.24947E+01 ** 0.52729E+00 *
*   24 ** 0.20177E+02 * 0.61040E+02 * 0.31875E+02 ** 0.25617E+01 * 0.44703E+01 * 0.26551E+01 ** 0.37768E+00 *
*   25 ** 0.15092E+01 * 0.12255E+01 * 0.31519E+02 ** 0.73547E+01 * 0.66394E+00 * 0.29793E+01 ** 0.52188E+00 *

 FIT IS STOPPED AFTER TOO MANY CONSECUTIVE DIVERGENCES. = 11
*   26 ** 0.43796E+02 *-0.51143E+01 * 0.20625E+02 ** 0.11540E+02 * 0.88807E+00 * 0.54676E+01 ** 0.98270E-01 *
*   27 ** 0.16061E+02 * 0.91559E+01 * 0.32823E+02 ** 0.35575E+01 * 0.86670E+00 * 0.27522E+01 ** 0.76970E+00 *
*   28 ** 0.20740E+02 * 0.30854E+02 * 0.34177E+02 ** 0.26042E+01 * 0.21929E+01 * 0.27126E+01 ** 0.54135E+00 *
*   29 ** 0.21517E+02 * 0.62047E+02 * 0.32873E+02 ** 0.26932E+01 * 0.46592E+01 * 0.27345E+01 ** 0.98208E+00 *
*   30 ** 0.94655E+00 * 0.11150E+01 * 0.31546E+02 ** 0.12129E+01 * 0.66071E+00 * 0.31689E+01 ** 0.51142E+00 *
*   31 ** 0.55204E+02 *-0.39181E+01 * 0.64749E+01 ** 0.86909E+01 * 0.79311E+00 * 0.46923E+01 ** 0.45367E-06 *
*   32 ** 0.20340E+02 * 0.97534E+01 * 0.32773E+02 ** 0.38121E+01 * 0.95553E+00 * 0.29752E+01 ** 0.61638E+00 *
*   33 ** 0.22129E+02 * 0.31098E+02 * 0.33624E+02 ** 0.27203E+01 * 0.22689E+01 * 0.27556E+01 ** 0.53579E+00 *
*   34 ** 0.21328E+02 * 0.60763E+02 * 0.32894E+02 ** 0.26334E+01 * 0.45055E+01 * 0.27592E+01 ** 0.97470E+00 *
*   35 **-0.31717E+02 *-0.31662E+01 * 0.43513E+02 ** 0.12633E+02 * 0.93494E+00 * 0.62111E+01 ** 0.18249E+00 *
*   36 **-0.16332E+01 *-0.11389E+01 * 0.74659E+02 ** 0.52275E+02 * 0.17646E+01 * 0.27846E+02 ** 0.24306E+00 *
*   37 ** 0.23016E+02 * 0.10086E+02 * 0.35541E+02 ** 0.38605E+01 * 0.97749E+00 * 0.31816E+01 ** 0.42674E+00 *
*   38 ** 0.24383E+02 * 0.30693E+02 * 0.35512E+02 ** 0.30283E+01 * 0.23521E+01 * 0.30768E+01 ** 0.95088E+00 *
*   39 ** 0.22864E+02 * 0.61287E+02 * 0.32688E+02 ** 0.27793E+01 * 0.46846E+01 * 0.28319E+01 ** 0.97661E+00 *
*   40 **-0.15403E+02 *-0.12853E+01 * 0.42176E+02 ** 0.83542E+01 * 0.79882E+00 * 0.44086E+01 ** 0.38526E+00 *
*   41 **-0.55638E+02 *-0.32754E+01 * 0.72742E+02 ** 0.42367E+02 * 0.15681E+01 * 0.23158E+02 ** 0.42512E+00 *
*   42 ** 0.19453E+02 * 0.97525E+01 * 0.37173E+02 ** 0.33465E+01 * 0.96334E+00 * 0.32975E+01 ** 0.50393E+00 *
*   43 ** 0.24177E+02 * 0.31538E+02 * 0.35103E+02 ** 0.29568E+01 * 0.24009E+01 * 0.26937E+01 ** 0.52848E+00 *
*   44 ** 0.23613E+02 * 0.61948E+02 * 0.33145E+02 ** 0.28571E+01 * 0.49284E+01 * 0.27984E+01 ** 0.47543E+00 *
*   45 **-0.98848E+01 *-0.37962E+00 * 0.41834E+02 ** 0.85220E+01 * 0.77005E+00 * 0.40311E+01 ** 0.45120E+00 *
*   46 **-0.60848E+02 *-0.20141E+01 * 0.66051E+02 ** 0.27320E+02 * 0.11594E+01 * 0.14807E+02 ** 0.58504E+00 *
*   47 ** 0.22879E+02 * 0.11159E+02 * 0.35829E+02 ** 0.41227E+01 * 0.10734E+01 * 0.37567E+01 ** 0.85138E+00 *
*   48 ** 0.27320E+02 * 0.32353E+02 * 0.37098E+02 ** 0.33013E+01 * 0.26276E+01 * 0.33669E+01 ** 0.94347E+00 *
*   49 ** 0.25600E+02 * 0.63236E+02 * 0.31948E+02 ** 0.30616E+01 * 0.51148E+01 * 0.29459E+01 ** 0.57920E+00 *
*   50 **-0.59511E+00 * 0.12837E+01 * 0.42043E+02 ** 0.76049E+01 * 0.74921E+00 * 0.35565E+01 ** 0.62191E+00 *
*   51 **-0.26637E+02 *-0.14411E+01 * 0.54232E+02 ** 0.15037E+02 * 0.89694E+00 * 0.75471E+01 ** 0.56111E+00 *
*   52 ** 0.25804E+02 * 0.13451E+02 * 0.39893E+02 ** 0.42439E+01 * 0.12409E+01 * 0.38477E+01 ** 0.85961E+00 *
*   53 ** 0.27366E+02 * 0.33934E+02 * 0.37384E+02 ** 0.33417E+01 * 0.27448E+01 * 0.33846E+01 ** 0.93558E+00 *
*   54 ** 0.24352E+02 * 0.62958E+02 * 0.31573E+02 ** 0.27247E+01 * 0.45740E+01 * 0.28736E+01 ** 0.97259E+00 *
*   55 ** 0.44732E+01 * 0.24755E+01 * 0.43134E+02 ** 0.65713E+01 * 0.75791E+00 * 0.34930E+01 ** 0.65712E+00 *
*   56 **-0.18644E+01 * 0.12399E+01 * 0.48580E+02 ** 0.86214E+01 * 0.48379E+00 * 0.42900E+01 ** 0.70265E+00 *
*   57 ** 0.39025E+02 * 0.15715E+02 * 0.39840E+02 ** 0.45804E+01 * 0.14820E+01 * 0.41121E+01 ** 0.87646E+00 *
*   58 ** 0.30843E+02 * 0.34299E+02 * 0.38048E+02 ** 0.34919E+01 * 0.29862E+01 * 0.36992E+01 ** 0.94307E+00 *
*   59 ** 0.28456E+02 * 0.61774E+02 * 0.32652E+02 ** 0.23515E+01 * 0.48979E+01 * 0.29561E+01 ** 0.96677E+00 *
*   60 ** 0.12431E+02 * 0.46541E+01 * 0.41895E+02 ** 0.58620E+01 * 0.78064E+00 * 0.36113E+01 ** 0.75677E+00 *
*   61 ** 0.26108E+02 * 0.70105E+01 * 0.42560E+02 ** 0.76404E+01 * 0.92914E+00 * 0.51647E+01 ** 0.47267E+00 *
*   62 ** 0.13025E+02 * 0.18709E+02 * 0.40670E+02 ** 0.47848E+01 * 0.17936E+01 * 0.43263E+01 ** 0.85000E+00 *
*   63 ** 0.13482E+02 * 0.45794E+02 * 0.38231E+02 ** 0.41535E+01 * 0.32793E+01 * 0.35113E+01 ** 0.94358E+00 *
*   64 ** 0.26633E+02 * 0.61256E+02 * 0.31702E+02 ** 0.31643E+01 * 0.52936E+01 * 0.29827E+01 ** 0.96850E+00 *
*   65 ** 0.18027E+02 * 0.70436E+01 * 0.42576E+02 ** 0.55668E+01 * 0.86744E+00 * 0.39652E+01 ** 0.80826E+00 *
*   66 ** 0.26634E+02 * 0.76467E+01 * 0.44339E+02 ** 0.64495E+01 * 0.96631E+00 * 0.50216E+01 ** 0.86210E+00 *
*   67 ** 0.36718E+02 * 0.21061E+02 * 0.40524E+02 ** 0.51623E+01 * 0.21203E+01 * 0.46004E+01 ** 0.50049E+00 *
*   68 ** 0.35017E+02 * 0.37297E+02 * 0.39134E+02 ** 0.41754E+01 * 0.35169E+01 * 0.41003E+01 ** 0.94595E+00 *
*   69 ** 0.27667E+02 * 0.54487E+02 * 0.32626E+02 ** 0.32065E+01 * 0.54163E+01 * 0.31126E+01 ** 0.97231E+00 *
*   70 ** 0.21973E+02 * 0.85491E+01 * 0.44132E+02 ** 0.54421E+01 * 0.95561E+00 * 0.43456E+01 ** 0.63593E+00 *
*   71 ** 0.13405E+02 * 0.12577E+02 * 0.44904E+02 ** 0.53056E+01 * 0.13946E+01 * 0.51003E+01 ** 0.86115E+00 *
*   72 ** 0.40264E+02 * 0.24919E+02 * 0.40542E+02 ** 0.55322E+01 * 0.26279E+01 * 0.47772E+01 ** 0.90546E+00 *
```

```
•  73 ** 0.37715E+02 • 0.40967E+02 • 0.38915E+02 ** 0.47609E+01 • 0.40618E+01 • 0.42950E+01 ** 0.95194E+00 •
•  74 ** 0.30422E+02 • 0.64197E+02 • 0.31589E+02 ** 0.36249E+01 • 0.56976E+01 • 0.32010E+01 ** 0.97241E+00 •
•  75 ** 0.31904E+02 • 0.13175E+02 • 0.42844E+02 ** 0.55069E+01 • 0.13528E+01 • 0.47642E+01 ** 0.87788E+00 •
•  76 ** 0.30789E+02 • 0.12653E+02 • 0.45126E+02 ** 0.55913E+01 • 0.13045E+01 • 0.49546E+01 ** 0.86293E+00 •
•  77 ** 0.41513E+02 • 0.27420E+02 • 0.42111E+02 ** 0.57713E+01 • 0.29650E+01 • 0.50577E+01 ** 0.91075E+00 •
•  78 ** 0.37131E+02 • 0.41573E+02 • 0.42015E+02 ** 0.47327E+01 • 0.40991E+01 • 0.45683E+01 ** 0.95146E+00 •
•  79 ** 0.28518E+02 • 0.64392E+02 • 0.34957E+02 ** 0.10790E+01 • 0.52225E+01 • 0.31070E+01 ** 0.96789E+00 •
•  80 ** 0.37627E+02 • 0.16723E+02 • 0.42401E+02 ** 0.57077E+01 • 0.17546E+01 • 0.49564E+01 ** 0.88757E+00 •
•  81 ** 0.41577E+02 • 0.17615E+02 • 0.42975E+02 ** 0.54320E+01 • 0.19753E+01 • 0.53961E+01 ** 0.88783E+00 •
•  82 ** 0.47163E+02 • 0.31506E+02 • 0.34748E+02 ** 0.65783E+01 • 0.36897E+01 • 0.50731E+01 ** 0.90864E+00 •
•  83 ** 0.40556E+02 • 0.44335E+02 • 0.29423E+02 ** 0.52320E+01 • 0.46436E+01 • 0.45814E+01 ** 0.94690E+00 •
•  84 ** 0.31114E+02 • 0.65074E+02 • 0.31520E+02 ** 0.37233E+01 • 0.59564E+01 • 0.32414E+01 ** 0.97076E+00 •
•  85 ** 0.42867E+02 • 0.21379E+02 • 0.42194E+02 ** 0.62702E+01 • 0.23901E+01 • 0.52757E+01 ** 0.90328E+00 •
•  86 ** 0.42903E+02 • 0.20767E+02 • 0.44362E+02 ** 0.64110E+01 • 0.23376E+01 • 0.55597E+01 ** 0.90164E+00 •
•  87 ** 0.45059E+02 • 0.36558E+02 • 0.39855E+02 ** 0.69153E+01 • 0.44129E+01 • 0.53422E+01 ** 0.91843E+00 •
•  88 ** 0.40210E+02 • 0.47243E+02 • 0.41568E+02 ** 0.52024E+01 • 0.49361E+01 • 0.47847E+01 ** 0.95491E+00 •
•  89 ** 0.29157E+02 • 0.65560E+02 • 0.33175E+02 ** 0.35046E+01 • 0.57983E+01 • 0.32695E+01 ** 0.97281E+00 •
•  90 ** 0.46157E+02 • 0.25065E+02 • 0.41148E+02 ** 0.66535E+01 • 0.29214E+01 • 0.53574E+01 ** 0.90187E+00 •
•  91 ** 0.52441E+02 • 0.27755E+02 • 0.40784E+02 ** 0.78547E+01 • 0.35505E+01 • 0.50181E+01 ** 0.90440E+00 •
•  92 ** 0.50716E+02 • 0.40131E+02 • 0.40360E+02 ** 0.72304E+01 • 0.49718E+01 • 0.55297E+01 ** 0.91907E+00 •
•  93 ** 0.41215E+02 • 0.49934E+02 • 0.43388E+02 ** 0.54025E+01 • 0.53303E+01 • 0.50731E+01 ** 0.95786E+00 •
•  94 ** 0.29136E+02 • 0.66825E+02 • 0.33213E+02 ** 0.34994E+01 • 0.58298E+01 • 0.32735E+01 ** 0.96558E+00 •
•  95 ** 0.47580E+02 • 0.29305E+02 • 0.41945E+02 ** 0.69228E+01 • 0.33582E+01 • 0.55264E+01 ** 0.90402E+00 •
•  96 ** 0.54678E+02 • 0.13279E+02 • 0.41059E+02 ** 0.80823E+01 • 0.43456E+01 • 0.59394E+01 ** 0.90594E+00 •
•  97 ** 0.53137E+02 • 0.44814E+02 • 0.40453E+02 ** 0.77370E+01 • 0.57681E+01 • 0.57449E+01 ** 0.92754E+00 •
•  98 ** 0.40603E+02 • 0.53835E+02 • 0.44529E+02 ** 0.53145E+01 • 0.57129E+01 • 0.51570E+01 ** 0.96501E+00 •
•  99 ** 0.30784E+02 • 0.67074E+02 • 0.32216E+02 ** 0.36611E+01 • 0.60191E+01 • 0.32836E+01 ** 0.96551E+00 •
• 100 ** 0.50856E+02 • 0.32801E+02 • 0.41271E+02 ** 0.73955E+01 • 0.40827E+01 • 0.56911E+01 ** 0.90795E+00 •
• 101 ** 0.55535E+02 • 0.37649E+02 • 0.39507E+02 ** 0.84186E+01 • 0.50462E+01 • 0.58656E+01 ** 0.89907E+00 •
• 102 ** 0.52947E+02 • 0.48303E+02 • 0.40494E+02 ** 0.76830E+01 • 0.62089E+01 • 0.57321E+01 ** 0.92263E+00 •
• 103 ** 0.44498E+02 • 0.57167E+02 • 0.42740E+02 ** 0.60025E+01 • 0.64924E+01 • 0.54238E+01 ** 0.96469E+00 •
• 104 ** 0.30458E+02 • 0.67835E+02 • 0.31769E+02 ** 0.35490E+01 • 0.60708E+01 • 0.32363E+01 ** 0.96581E+00 •
• 105 ** 0.54505E+02 • 0.38012E+02 • 0.39024E+02 ** 0.80716E+01 • 0.49819E+01 • 0.56606E+01 ** 0.90128E+00 •
• 106 ** 0.58859E+02 • 0.42342E+02 • 0.37625E+02 ** 0.90692E+01 • 0.59061E+01 • 0.58395E+01 ** 0.89193E+00 •
• 107 ** 0.53310E+02 • 0.52639E+02 • 0.40050E+02 ** 0.70685E+01 • 0.68673E+01 • 0.57535E+01 ** 0.92471E+00 •
• 108 ** 0.45554E+02 • 0.59976E+02 • 0.43427E+02 ** 0.62016E+01 • 0.69466E+01 • 0.54915E+01 ** 0.96548E+00 •
• 109 ** 0.31832E+02 • 0.68031E+02 • 0.28750E+02 ** 0.37936E+01 • 0.62492E+01 • 0.30609E+01 ** 0.95350E+00 •
• 110 ** 0.57121E+02 • 0.43230E+02 • 0.36881E+02 ** 0.86146E+01 • 0.58784E+01 • 0.55973E+01 ** 0.89831E+00 •
• 111 ** 0.56035E+02 • 0.47793E+02 • 0.37312E+02 ** 0.88344E+01 • 0.65968E+01 • 0.57228E+01 ** 0.89894E+00 •
• 112 ** 0.53214E+02 • 0.55678E+02 • 0.41166E+02 ** 0.77530E+01 • 0.73420E+01 • 0.58560E+01 ** 0.92675E+00 •
• 113 ** 0.44531E+02 • 0.63727E+02 • 0.44845E+02 ** 0.60405E+01 • 0.72975E+01 • 0.55935E+01 ** 0.91967E+00 •
• 114 ** 0.30763E+02 • 0.70009E+02 • 0.31712E+02 ** 0.36910E+01 • 0.63229E+01 • 0.32597E+01 ** 0.96740E+00 •
• 115 ** 0.59245E+02 • 0.48980E+02 • 0.36312E+02 ** 0.91192E+01 • 0.68719E+01 • 0.56859E+01 ** 0.90045E+00 •
• 116 ** 0.59659E+02 • 0.53177E+02 • 0.35691E+02 ** 0.92761E+01 • 0.[illegible]395E+01 • 0.56482E+01 ** 0.88147E+00 •
• 117 ** 0.57635E+02 • 0.65559E+02 • 0.36492E+02 ** 0.88016E+01 • 0.91150E+01 • 0.56409E+01 ** 0.92401E+00 •
• 118 ** 0.47461E+02 • 0.66186E+02 • 0.46515E+02 ** 0.58827E+01 • 0.74853E+01 • 0.56955E+01 ** 0.97107E+00 •
• 119 ** 0.31212E+02 • 0.69565E+02 • 0.29656E+02 ** 0.37354E+01 • 0.61331E+01 • 0.30624E+01 ** 0.96366E+00 •
• 120 ** 0.60251E+02 • 0.54537E+02 • 0.34506E+02 ** 0.93527E+01 • 0.77668E+01 • 0.55168E+01 ** 0.89063E+00 •
• 121 ** 0.63427E+02 • 0.60267E+02 • 0.34363E+02 ** 0.10192E+02 • 0.89755E+01 • 0.57407E+01 ** 0.88615E+00 •
• 122 ** 0.58529E+02 • 0.72126E+02 • 0.37040E+02 ** 0.91143E+01 • 0.10236E+02 • 0.58290E+01 ** 0.93509E+00 •
• 123 ** 0.44879E+02 • 0.69369E+02 • 0.45094E+02 ** 0.61352E+01 • 0.80446E+01 • 0.56766E+01 ** 0.96975E+00 •
• 124 ** 0.30780E+02 • 0.70093E+02 • 0.28251E+02 ** 0.36647E+01 • 0.61381E+01 • 0.29764E+01 ** 0.96768E+00 •
• 125 ** 0.63013E+02 • 0.62376E+02 • 0.33647E+02 ** 0.10080E+02 • 0.92452E+01 • 0.56173E+01 ** 0.85942E+00 •
• 126 ** 0.69346E+02 • 0.70472E+02 • 0.31715E+02 ** 0.11551E+02 • 0.11182E+02 • 0.57318E+01 ** 0.90237E+00 •
• 127 ** 0.58954E+02 • 0.76987E+02 • 0.37505E+02 ** 0.89499E+01 • 0.10856E+02 • 0.58491E+01 ** 0.94073E+00 •
• 128 ** 0.44266E+02 • 0.72046E+02 • 0.45001E+02 ** 0.60377E+01 • 0.84047E+01 • 0.56308E+01 ** 0.97228E+00 •
• 129 ** 0.29763E+02 • 0.69464E+02 • 0.26058E+02 ** 0.35008E+01 • 0.61639E+01 • 0.27413E+01 ** 0.95502E+00 •
• 130 ** 0.64450E+02 • 0.70752E+02 • 0.33741E+02 ** 0.10515E+02 • 0.10744E+02 • 0.57658E+01 ** 0.91367E+00 •
• 131 ** 0.65809E+02 • 0.76592E+02 • 0.33532E+02 ** 0.10919E+02 • 0.11872E+02 • 0.55076E+01 ** 0.91203E+00 •
• 132 ** 0.56273E+02 • 0.81413E+02 • 0.37460E+02 ** 0.85427E+01 • 0.11255E+02 • 0.57224E+01 ** 0.94115E+00 •
```

THE UNIVERSITY OF ALBERTA

```
*  133 ** 0.42014E+02 * 0.77429E+02 * 0.45476E+02 ** 0.56727E+01 * 0.86857E+01 * 0.35660E+01 ** 0.97661E+00 *
*  134 ** 0.30965E+02 * 0.68606E+02 * 0.28025E+02 ** 0.46357E+01 * 0.61772E+01 * 0.29419E+01 ** 0.96157E+00 *
*  135 ** 0.61572E+02 * 0.76640E+02 * 0.30995E+02 ** 0.10303E+02 * 0.11550E+02 * 0.58225E+01 ** 0.92185E+00 *
*  136 ** 0.65691E+02 * 0.84070E+02 * 0.31581E+02 ** 0.10909E+02 * 0.13058E+02 * 0.55778E+01 ** 0.90241E+00 *
*  137 ** 0.53601E+02 * 0.83927E+02 * 0.38760E+02 ** 0.79557E+01 * 0.11225E+02 * 0.56964E+01 ** 0.98331E+00 *
*  138 ** 0.40670E+02 * 0.78656E+02 * 0.45181E+02 ** 0.54715E+01 * 0.86999E+01 * 0.53071E+01 ** 0.97454E+00 *
*  139 ** 0.32021E+02 * 0.66905E+02 * 0.28667E+02 ** 0.37977E+01 * 0.63704E+01 * 0.28214E+01 ** 0.95394E+00 *
*  140 ** 0.62247E+02 * 0.91876E+02 * 0.32867E+02 ** 0.99800E+01 * 0.12190E+02 * 0.55220E+01 ** 0.91237E+00 *
*  141 ** 0.66239E+02 * 0.93411E+02 * 0.29423E+02 ** 0.11103E+02 * 0.14674E+02 * 0.53387E+01 ** 0.90700E+00 *
*  142 ** 0.54414E+02 * 0.91097E+02 * 0.35765E+02 ** 0.81701E+01 * 0.12400E+02 * 0.53983E+01 ** 0.94241E+00 *
*  143 ** 0.25559E+02 * 0.93071E+02 * 0.34055E+02 ** 0.52633E+01 * 0.90306E+01 * 0.51947E+01 ** 0.97765E+00 *
*  144 ** 0.31728E+02 * 0.68581E+02 * 0.26131E+02 ** 0.17539E+01 * 0.62920E+01 * 0.28447E+01 ** 0.95573E+00 *
*  145 ** 0.56479E+02 * 0.85498E+02 * 0.34139E+02 ** 0.99772E+01 * 0.12192E+02 * 0.54577E+01 ** 0.91424E+00 *
*  146 ** 0.62225E+02 * 0.99460E+02 * 0.30416E+02 ** 0.13109E+02 * 0.15023E+02 * 0.52570E+01 ** 0.91269E+00 *
*  147 ** 0.51077E+02 * 0.94858E+02 * 0.36025E+02 ** 0.74624E+01 * 0.12404E+02 * 0.52258E+01 ** 0.94811E+00 *
*  148 ** 0.38671E+02 * 0.86125E+02 * 0.42486E+02 ** 0.51178E+01 * 0.92706E+01 * 0.49770E+01 ** 0.97578E+00 *
*  149 ** 0.33956E+02 * 0.67537E+02 * 0.25585E+02 ** 0.40233E+01 * 0.64056E+01 * 0.28946E+01 ** 0.94787E+00 *
*  150 ** 0.53382E+02 * 0.87031E+02 * 0.34244E+02 ** 0.79905E+01 * 0.11619E+02 * 0.51076E+01 ** 0.90475E+00 *
*  151 ** 0.57234E+02 * 0.10728E+03 * 0.32054E+02 ** 0.89584E+01 * 0.15419E+02 * 0.52080E+01 ** 0.93068E+00 *
*  152 ** 0.48124E+02 * 0.99391E+02 * 0.36379E+02 ** 0.69977E+01 * 0.12562E+02 * 0.50898E+01 ** 0.95699E+00 *
*  153 ** 0.36937E+02 * 0.88877E+02 * 0.41169E+02 ** 0.48470E+01 * 0.93477E+01 * 0.47266E+01 ** 0.98306E+00 *
*  154 ** 0.34734E+02 * 0.68560E+02 * 0.25014E+02 ** 0.41798E+01 * 0.66361E+01 * 0.29078E+01 ** 0.95365E+00 *
*  155 ** 0.57286E+02 * 0.10343E+03 * 0.32240E+02 ** 0.86921E+01 * 0.14619E+02 * 0.51496E+01 ** 0.93682E+00 *
*  156 ** 0.62815E+02 * 0.11393E+03 * 0.32665E+02 ** 0.80184E+01 * 0.15656E+02 * 0.51777E+01 ** 0.94968E+00 *
*  157 ** 0.44563E+02 * 0.10367E+03 * 0.28594E+02 ** 0.62407E+01 * 0.12556E+02 * 0.51279E+01 ** 0.96871E+00 *
*  158 ** 0.24013E+02 * 0.48159E+02 * 0.37623E+02 ** 0.43550E+01 * 0.88055E+01 * 0.41670E+01 ** 0.98209E+00 *
*  159 ** 0.35322E+02 * 0.67205E+02 * 0.22774E+02 ** 0.47423E+01 * 0.65603E+01 * 0.27437E+01 ** 0.94439E+00 *
*  160 ** 0.53466E+02 * 0.10901E+03 * 0.34959E+02 ** 0.81202E+01 * 0.15004E+02 * 0.53440E+01 ** 0.95374E+00 *
*  161 ** 0.48559E+02 * 0.12916E+03 * 0.33637E+02 ** 0.71791E+01 * 0.15801E+02 * 0.49441E+01 ** 0.95961E+00 *
*  162 ** 0.41211E+02 * 0.10673E+03 * 0.36618E+02 ** 0.56505E+01 * 0.12396E+02 * 0.46937E+01 ** 0.96556E+00 *
*  163 ** 0.32068E+02 * 0.84787E+02 * 0.35822E+02 ** 0.40625E+01 * 0.85966E+01 * 0.38529E+01 ** 0.96232E+00 *
*  164 ** 0.35187E+02 * 0.64207E+02 * 0.22084E+02 ** 0.41993E+01 * 0.62285E+01 * 0.20650E+01 ** 0.91728E+00 *
*  165 ** 0.46455E+02 * 0.11319E+03 * 0.35461E+02 ** 0.70883E+01 * 0.14690E+02 * 0.51082E+01 ** 0.95567E+00 *
*  166 ** 0.43765E+02 * 0.12454E+03 * 0.35670E+02 ** 0.62238E+01 * 0.15470E+02 * 0.48924E+01 ** 0.97290E+00 *
*  167 ** 0.31764E+02 * 0.11262E+03 * 0.39697E+02 ** 0.52436E+01 * 0.12639E+02 * 0.48842E+01 ** 0.98282E+00 *
*  168 ** 0.31559E+02 * 0.93117E+02 * 0.35854E+02 ** 0.40426E+01 * 0.90480E+01 * 0.38683E+01 ** 0.96046E+00 *
*  169 ** 0.38355E+02 * 0.63767E+02 * 0.22179E+02 ** 0.47056E+01 * 0.65328E+01 * 0.20331E+01 ** 0.93078E+00 *
*  170 ** 0.43468E+02 * 0.11922E+03 * 0.37494E+02 ** 0.61874E+01 * 0.14510E+02 * 0.50539E+01 ** 0.97240E+00 *
*  171 ** 0.37634E+02 * 0.12785E+03 * 0.37435E+02 ** 0.51253E+01 * 0.14891E+02 * 0.47739E+01 ** 0.98245E+00 *
*  172 ** 0.22755E+02 * 0.11397E+03 * 0.39271E+02 ** 0.44280E+01 * 0.11950E+02 * 0.44872E+01 ** 0.98820E+00 *
*  173 ** 0.26181E+02 * 0.85113E+02 * 0.32757E+02 ** 0.35236E+01 * 0.79823E+01 * 0.32413E+01 ** 0.98565E+00 *
*  174 ** 0.37947E+02 * 0.63550E+02 * 0.20994E+02 ** 0.48122E+01 * 0.64521E+01 * 0.27000E+01 ** 0.90493E+00 *
*  175 ** 0.38935E+02 * 0.12075E+03 * 0.30578E+02 ** 0.54309E+01 * 0.14025E+02 * 0.48653E+01 ** 0.96127E+00 *
*  176 ** 0.31057E+02 * 0.12992E+03 * 0.39678E+02 ** 0.41640E+01 * 0.13945E+02 * 0.46112E+01 ** 0.99020E+00 *
*  177 ** 0.27737E+02 * 0.11140E+03 * 0.40627E+02 ** 0.38096E+01 * 0.11141E+02 * 0.43049E+01 ** 0.99320E+00 *
*  178 ** 0.26518E+02 * 0.98871E+02 * 0.31370E+02 ** 0.11708E+01 * 0.79003E+01 * 0.21651E+01 ** 0.95578E+00 *
*  179 ** 0.37052E+02 * 0.59636E+02 * 0.21972E+02 ** 0.44715E+01 * 0.59477E+01 * 0.27190E+01 ** 0.88615E+00 *
*  180 ** 0.32298E+02 * 0.12281E+03 * 0.40213E+02 ** 0.44654E+01 * 0.13123E+02 * 0.46547E+01 ** 0.98546E+00 *
*  181 ** 0.24255E+02 * 0.13111E+03 * 0.39813E+02 ** 0.36698E+01 * 0.13005E+02 * 0.42570E+01 ** 0.99499E+00 *
*  182 ** 0.23147E+02 * 0.11279E+03 * 0.38419E+02 ** 0.32731E+01 * 0.10317E+02 * 0.38230E+01 ** 0.99595E+00 *
*  183 ** 0.28067E+02 * 0.85637E+02 * 0.34771E+02 ** 0.36993E+01 * 0.81335E+01 * 0.31029E+01 ** 0.99649E+00 *
*  184 ** 0.37441E+02 * 0.59242E+02 * 0.20097E+02 ** 0.46575E+01 * 0.61450E+01 * 0.27572E+01 ** 0.87726E+00 *
*  185 ** 0.25711E+02 * 0.12420E+03 * 0.41669E+02 ** 0.36945E+01 * 0.12253E+02 * 0.44402E+01 ** 0.95428E+00 *
*  186 ** 0.17944E+02 * 0.12776E+03 * 0.40586E+02 ** 0.21709E+01 * 0.11699E+02 * 0.39749E+01 ** 0.95706E+00 *
*  187 ** 0.19166E+02 * 0.10757E+03 * 0.38112E+02 ** 0.29734E+01 * 0.91635E+01 * 0.35305E+01 ** 0.99649E+00 *
*  188 ** 0.25617E+02 * 0.77321E+02 * 0.28057E+02 ** 0.40093E+01 * 0.64962E+01 * 0.27428E+01 ** 0.98372E+00 *
*  189 ** 0.40474E+02 * 0.56148E+02 * 0.22132E+02 ** 0.50294E+01 * 0.59050E+01 * 0.28946E+01 ** 0.86724E+00 *
*  190 ** 0.20057E+02 * 0.12114E+03 * 0.43154E+02 ** 0.31515E+01 * 0.11064E+02 * 0.42089E+01 ** 0.95703E+00 *
*  191 ** 0.11402E+02 * 0.12472E+03 * 0.25516E+02 ** 0.25271E+01 * 0.10647E+02 * 0.35963E+01 ** 0.95929E+00 *
*  192 ** 0.15366E+02 * 0.10124E+03 * 0.36415E+02 ** 0.25797E+01 * 0.62943E+01 * 0.31987E+01 ** 0.95838E+00 *
```

THE UNIVERSITY OF ALBERTA

```
*  193 **  0.27152E+02 *  0.73392E+02 *  0.25304E+02 **  0.30940E+01 *  0.61601E+01 *  0.25398E+01 **  0.98500E+00 *
*  194 **  0.42714E+02 *  0.56020E+02 *  0.21896E+02 **  0.54063E+01 *  0.60993E+01 *  0.29642E+01 **  0.68510E+00 *
*  195 **  0.14394E+02 *  0.11746E+03 *  0.42167E+02 **  0.27013E+01 *  0.99561E+01 *  0.36088E+01 **  0.99883E+00 *
*  196 **  0.63495E+01 *  0.11645E+03 *  0.38874E+02 **  0.22596E+01 *  0.92825E+01 *  0.32437E+01 **  0.99975E+00 *
*  197 **  0.14269E+02 *  0.94618E+02 *  0.34591E+02 **  0.23865E+01 *  0.71606E+01 *  0.26917E+01 **  0.99592E+00 *
*  198 **  0.25744E+02 *  0.64616E+02 *  0.25541E+02 **  0.24924E+01 *  0.52594E+01 *  0.24823E+01 **  0.97294E+00 *
*  199 **  0.40605E+02 *  0.53992E+02 *  0.24692E+02 **  0.50595E+01 *  0.56740E+01 *  0.31237E+01 **  0.89279E+00 *
*  200 **  0.90173E+01 *  0.11002E+03 *  0.41269E+02 **  0.23759E+01 *  0.86225E+01 *  0.34394E+01 **  0.99952E+00 *
*  201 **  0.17262E+01 *  0.10617E+03 *  0.37021E+02 **  0.20343E+01 *  0.79325E+01 *  0.29424E+01 **  0.99999E+00 *
*  202 **  0.13066E+02 *  0.83552E+02 *  0.13505E+02 **  0.22213E+01 *  0.59121E+01 *  0.26404E+01 **  0.99851E+00 *
*  203 **  0.22015E+02 *  0.75812E+02 *  0.25197E+02 **  0.29608E+01 *  0.44776E+01 *  0.24231E+01 **  0.95111E+00 *
*  204 **  0.46748E+02 *  0.57092E+02 *  0.24874E+02 **  0.42126E+01 *  0.67188E+01 *  0.35066E+01 **  0.92618E+00 *
*  205 **  0.56054E+01 *  0.99615E+02 *  0.39092E+02 **  0.21585E+01 *  0.72508E+01 *  0.30402E+01 **  0.99968E+00 *
*  206 ** -0.14914E+01 *  0.95024E+02 *  0.34997E+02 **  0.17398E+01 *  0.67085E+01 *  0.26308E+01 **  0.99998E+00 *
*  207 **  0.13284E+02 *  0.71910E+02 *  0.31262E+02 **  0.21215E+01 *  0.48303E+01 *  0.23825E+01 **  0.99867E+00 *
*  208 **  0.29615E+02 *  0.51106E+02 *  0.25564E+02 **  0.34034E+01 *  0.43629E+01 *  0.26161E+01 **  0.96277E+00 *
*  209 **  0.47216E+02 *  0.55591E+02 *  0.24621E+02 **  0.52920E+01 *  0.65071E+01 *  0.34379E+01 **  0.92466E+00 *
*  210 **  0.41374E+01 *  0.86238E+02 *  0.37014E+02 **  0.20205E+01 *  0.60903E+01 *  0.27749E+01 **  0.99994E+00 *
*  211 ** -0.75544E+01 *  0.79112E+02 *  0.33173E+02 **  0.17093E+01 *  0.50733E+01 *  0.23164E+01 **  0.99981E+00 *
*  212 **  0.15410E+02 *  0.61159E+02 *  0.31213E+02 **  0.22103E+01 *  0.40690E+01 *  0.23742E+01 **  0.99967E+00 *
*  213 **  0.30929E+02 *  0.42256E+02 *  0.24805E+02 **  0.35534E+01 *  0.36690E+01 *  0.26013E+01 **  0.97156E+00 *
*  214 **  0.49563E+02 *  0.52847E+02 *  0.24631E+02 **  0.67701E+01 *  0.64017E+01 *  0.36220E+01 **  0.91139E+00 *
*  215 **  0.47762E+01 *  0.74464E+02 *  0.24989E+02 **  0.19225E+01 *  0.46870E+01 *  0.24179E+01 **  0.10000E+01 *
*  216 **  0.37559E+01 *  0.62639E+02 *  0.30663E+02 **  0.17819E+01 *  0.37447E+01 *  0.20407E+01 **  0.99737E+00 *
*  217 **  0.19414E+02 *  0.44868E+02 *  0.28087E+02 **  0.24126E+01 *  0.32298E+01 *  0.23781E+01 **  0.99739E+00 *
*  218 **  0.32520E+02 *  0.34696E+02 *  0.25658E+02 **  0.38035E+01 *  0.31016E+01 *  0.27472E+01 **  0.90194E+00 *
*  219 **  0.49104E+02 *  0.49835E+02 *  0.23551E+02 **  0.66662E+01 *  0.59899E+01 *  0.35147E+01 **  0.88874E+00 *
*  220 **  0.82080E+01 *  0.58368E+02 *  0.32984E+02 **  0.19363E+01 *  0.35212E+01 *  0.22141E+01 **  0.99996E+00 *
*  221 **  0.11051E+02 *  0.40122E+02 *  0.28274E+02 **  0.19833E+01 *  0.27208E+01 *  0.19521E+01 **  0.99201E+00 *
*  222 **  0.24265E+02 *  0.34099E+02 *  0.28665E+02 **  0.24979E+01 *  0.25751E+01 *  0.25331E+01 **  0.99216E+00 *
*  223 **  0.13478E+02 *  0.29491E+02 *  0.29221E+02 **  0.40583E+01 *  0.26095E+01 *  0.31176E+01 **  0.87755E+00 *
*  224 **  0.50649E+02 *  0.50045E+02 *  0.25061E+02 **  0.69989E+01 *  0.61529E+01 *  0.37238E+01 **  0.90520E+00 *
*  225 **  0.14405E+02 *  0.41074E+02 *  0.31394E+02 **  0.21478E+01 *  0.25558E+01 *  0.22266E+01 **  0.99999E+00 *
*  226 **  0.15331E+02 *  0.17735E+02 *  0.25556E+02 **  0.22104E+01 *  0.12638E+01 *  0.19586E+01 **  0.96408E+00 *
*  227 **  0.26140E+02 *  0.19534E+02 *  0.23060E+02 **  0.32231E+01 *  0.16175E+01 *  0.23402E+01 **  0.58010E+00 *
*  228 **  0.34889E+02 *  0.23661E+02 *  0.22575E+02 **  0.42527E+01 *  0.22561E+01 *  0.26444E+01 **  0.70069E+00 *
*  229 **  0.45197E+02 *  0.43619E+02 *  0.20091E+02 **  0.54718E+01 *  0.49567E+01 *  0.29108E+01 **  0.65956E+00 *
*  230 **  0.25254E+02 *  0.25845E+02 *  0.20704E+02 **  0.35661E+01 *  0.20283E+01 *  0.27900E+01 **  0.10000E+01 *
*  231 **  0.40423E+02 *  0.76777E+01 *  0.27096E+02 **  0.48852E+01 *  0.10653E+01 *  0.45744E+01 **  0.99507E+00 *
*  232 **  0.44514E+02 *  0.16531E+02 *  0.27641E+02 **  0.66930E+01 *  0.19180E+01 *  0.35548E+01 **  0.95321E+00 *
*  233 **  0.48356E+02 *  0.26791E+02 *  0.25867E+02 **  0.67067E+01 *  0.31812E+01 *  0.37276E+01 **  0.90027E+00 *
*  234 **  0.54678E+02 *  0.49725E+02 *  0.25900E+02 **  0.79880E+01 *  0.63485E+01 *  0.40591E+01 **  0.90592E+00 *
*  235 **  0.39605E+02 *  0.10767E+02 *  0.30917E+02 **  0.73294E+01 *  0.12896E+01 *  0.44396E+01 **  0.99999E+00 *
*  236 **  0.52142E+02 * -0.31394E+01 *  0.21410E+02 **  0.24153E+02 *  0.15397E+01 *  0.12520E+02 **  0.99624E+00 *
*  237 **  0.39732E+02 *  0.86690E+01 *  0.34927E+02 **  0.93177E+01 *  0.11125E+01 *  0.51576E+01 **  0.93232E+00 *
*  238 **  0.44274E+02 *  0.22641E+02 *  0.28582E+02 **  0.60644E+01 *  0.25443E+01 *  0.30873E+01 **  0.85712E+00 *
*  239 **  0.53035E+02 *  0.49559E+02 *  0.26006E+02 **  0.75570E+01 *  0.59753E+01 *  0.42919E+01 **  0.91276E+00 *
*  240 **  0.39556E+02 *  0.10575E+00 *  0.39233E+02 **  0.33847E+02 *  0.14383E+01 *  0.13669E+02 **  0.94857E+00 *
*  241 **  0.67179E+02 * -0.70179E+01 *  0.33986E+02 **  0.22982E+02 *  0.16519E+01 *  0.11005E+02 **  0.98478E+00 *
*  242 **  0.26262E+02 *  0.45994E+01 *  0.44813E+02 **  0.11256E+02 *  0.85552E+00 *  0.60025E+01 **  0.66445E+00 *
*  243 **  0.48984E+02 *  0.22183E+02 *  0.28713E+02 **  0.70078E+01 *  0.28030E+01 *  0.41274E+01 **  0.88361E+00 *
*  244 **  0.54788E+02 *  0.48201E+02 *  0.29713E+02 **  0.79634E+01 *  0.63132E+01 *  0.45187E+01 **  0.91784E+00 *
*  245 **  0.99606E+02 * -0.77351E+01 *  0.18950E+02 **  0.43901E+02 *  0.17131E+01 *  0.13259E+02 **  0.75952E+00 *
*  246 **  0.25173E+02 * -0.10531E+02 * -0.57167E+02 **  0.10629E+03 *  0.58735E+01 *  0.58325E+02 **  0.55543E+00 *
*  247 ** -0.87133E+01 *  0.10471E+01 *  0.61282E+02 **  0.16479E+02 *  0.92098E+00 *  0.76284E+01 **  0.50055E+00 *
*  248 **  0.43975E+02 *  0.20259E+02 *  0.31368E+02 **  0.61936E+01 *  0.22893E+01 *  0.41306E+01 **  0.44548E+00 *
*  249 **  0.54632E+02 *  0.45411E+02 *  0.30768E+02 **  0.70219E+01 *  0.59250E+01 *  0.40249E+01 **  0.90976E+00 *
*  250 **  0.41708E+03 * -0.12942E+02 * -0.12716E+02 **  0.53748E+03 *  0.13585E+02 *  0.21346E+03 **  0.75821E+00 *
*  251 ** -0.41257E+02 * -0.20394E+01 *  0.81969E+02 **  0.25081E+02 *  0.11633E+01 *  0.14597E+02 **  0.52560E+00 *
*  252 **  0.11008E+02 *  0.35693E+01 *  0.56203E+02 **  0.10859E+02 *  0.85877E+00 *  0.58304E+01 **  0.53034E+00 *
```

```
 *  253 **  0.33906E+02 *  0.17625E+02 *  0.17224E+02 **  0.43990E+01 *  0.16684E+01 *  0.41129E+01 **  0.42821E+00 *
 *  254 **  0.51514E+02 *  0.44561E+02 *  0.32417E+02 **  0.72655E+01 *  0.55649E+01 *  0.46134E+01 **  0.70119E+00 *
 *  255 ** -0.12264E+03 * -0.80473E+00 *  0.11940E+03 **  0.10759E+03 *  0.27895E+01 *  0.55750E+02 **  0.17452E+00 *
 *  256 **  0.11994E+02 *  0.41362E+01 *  0.59779E+02 **  0.10321E+02 *  0.88946E+00 *  0.61018E+01 **  0.85051E+00 *
 *  257 **  0.21467E+02 *  0.62165E+01 *  0.54547E+02 **  0.85772E+01 *  0.93091E+00 *  0.55938E+01 **  0.85392E+00 *
 *  258 **  0.40577E+02 *  0.26549E+02 *  0.41143E+02 **  0.59377E+01 *  0.22115E+01 *  0.50058E+01 **  0.86726E+00 *
 *  259 **  0.54712E+02 *  0.45991E+02 *  0.34725E+02 **  0.60091E+01 *  0.60349E+01 *  0.51227E+01 **  0.91935E+00 *
 *  260 ** -0.23642E+02 *  0.11656E+01 *  0.80013E+02 **  0.21153E+02 *  0.12114E+01 *  0.14350E+02 **  0.94155E+00 *
 *  261 **  0.36806E+02 *  0.10687E+02 *  0.50345E+02 **  0.79115E+01 *  0.13004E+01 *  0.65370E+01 **  0.95550E+00 *
 *  262 **  0.42009E+02 *  0.13349E+02 *  0.46829E+02 **  0.75821E+01 *  0.16085E+01 *  0.62501E+01 **  0.86594E+00 *
 *  263 **  0.43049E+02 *  0.21376E+02 *  0.43011E+02 **  0.63260E+01 *  0.23996E+01 *  0.53866E+01 **  0.85433E+00 *
 *  264 **  0.54154E+02 *  0.47003E+02 *  0.37200E+02 **  0.79166E+01 *  0.59993E+01 *  0.54215E+01 **  0.92217E+00 *
NEGATIVE VARIANCE FOR THE 7TH MEASURED VARIABLE=-0.40442E-03
 *  265 **  0.17453E+02 *  0.35215E+01 *  0.66404E+02 **  0.21030E+02 *  0.11631E+01 *  0.10416E+02 **  0.96213E+00 *
 *  266 **  0.64482E+02 *  0.21745E+02 *  0.19490E+02 **  0.11107E+02 *  0.32487E+01 *  0.60273E+01 **  0.95702E+00 *
 *  267 **  0.61786E+02 *  0.20609E+02 *  0.41251E+02 **  0.10561E+02 *  0.30556E+01 *  0.68943E+01 **  0.98276E+00 *
 *  268 **  0.44734E+02 *  0.21072E+02 *  0.46506E+02 **  0.67554E+01 *  0.25303E+01 *  0.60006E+01 **  0.90831E+00 *
 *  269 **  0.57059E+02 *  0.48176E+02 *  0.37327E+02 **  0.85039E+01 *  0.65613E+01 *  0.56615E+01 **  [illegible]  *
 *  270 **  0.51551E+02 *  0.62100E+01 *  0.54871E+02 **  0.17421E+02 *  0.13108E+01 *  0.11044E+02 **  0.15856E+00 *
 *  271 **  0.60163E+02 *  0.20790E+02 *  0.43514E+02 **  0.10200E+02 *  0.30216E+01 *  0.70670E+01 **  0.96096E+00 *
 *  272 **  0.63151E+02 *  0.23713E+02 *  0.43116E+02 **  0.10765E+02 *  0.35594E+01 *  0.72084E+01 **  0.95616E+00 *
 *  273 **  0.55720E+02 *  0.27097E+02 *  0.45074E+02 **  0.87675E+01 *  0.36595E+01 *  0.67263E+01 **  0.92597E+00 *
 *  274 **  0.58070E+02 *  0.49195E+02 *  0.38111E+02 **  0.88507E+01 *  0.68285E+01 *  0.58458E+01 **  0.97355E+00 *
 *  275 **  0.26552E+02 *  0.11268E+02 *  0.65874E+02 **  0.72058E+01 *  0.12719E+01 *  0.72446E+01 **  0.90467E+00 *
 *  276 **  0.70508E+02 *  0.24193E+02 *  0.41081E+02 **  0.12763E+02 *  0.39691E+01 *  0.75420E+01 **  0.87616E+00 *
 *  277 **  0.69222E+02 *  0.25250E+02 *  0.40453E+02 **  0.12304E+02 *  0.40693E+01 *  0.73019E+01 **  0.96790E+00 *
 *  278 **  0.55652E+02 *  0.26740E+02 *  0.44514E+02 **  0.87492E+01 *  0.36067E+01 *  0.66463E+01 **  0.92524E+00 *
 *  279 **  0.57910E+02 *  0.44266E+02 *  0.39308E+02 **  0.99301E+01 *  0.66748E+01 *  0.55905E+01 **  0.92607E+00 *
 *  280 **  0.26281E+02 *  0.11170E+02 *  0.66701E+02 **  0.71006E+01 *  0.12694E+01 *  0.73473E+01 **  0.90677E+00 *
 *  281 **  0.73204E+02 *  0.27067E+02 *  0.39753E+02 **  0.11397E+02 *  0.45660E+01 *  0.74807E+01 **  0.95512E+00 *
 *  282 **  0.68167E+02 *  0.26407E+02 *  0.42642E+02 **  0.11428E+02 *  0.41010E+01 *  0.73492E+01 **  [illegible]  *
 *  283 **  0.58428E+02 *  0.29555E+02 *  0.44773E+02 **  0.91029E+01 *  0.41895E+01 *  0.68089E+01 **  0.92720E+00 *
 *  284 **  0.59344E+02 *  0.50710E+02 *  0.37949E+02 **  0.91619E+01 *  0.71379E+01 *  0.59137E+01 **  0.92234E+00 *
 *  285 **  0.36259E+02 *  0.15550E+02 *  0.62095E+02 **  0.71039E+01 *  0.17374E+01 *  0.74514E+01 **  0.90435E+00 *
 *  286 **  0.76736E+02 *  0.31239E+02 *  0.42859E+02 **  0.14449E+02 *  0.54832E+01 *  0.82911E+01 **  0.98483E+00 *
 *  287 **  0.72717E+02 *  0.30129E+02 *  0.43871E+02 **  0.13242E+02 *  0.50588E+01 *  0.81129E+01 **  0.95701E+00 *
 *  288 **  0.56840E+02 *  0.29100E+02 *  0.47543E+02 **  0.99102E+01 *  0.40211E+01 *  0.71496E+01 **  0.92222E+00 *
 *  289 **  0.52302E+02 *  0.51444E+02 *  0.39747E+02 **  0.99464E+01 *  0.76247E+01 *  0.64346E+01 **  0.93577E+00 *
 *  290 **  0.37155E+02 *  0.16782E+02 *  0.65086E+02 **  0.71678E+01 *  0.18817E+01 *  0.78420E+01 **  0.91362E+00 *
 *  291 **  0.85700E+02 *  0.37522E+02 *  0.49716E+02 **  0.17564E+02 *  0.72971E+01 *  0.10457E+02 **  0.33310E+00 *
 *  292 **  0.82166E+02 *  0.36016E+02 *  0.50598E+02 **  0.16353E+02 *  0.67574E+01 *  0.10363E+02 **  0.96275E+00 *
 *  293 **  0.66479E+02 *  0.34054E+02 *  0.55062E+02 **  0.11593E+02 *  0.53490E+01 *  0.93261E+01 **  0.96027E+00 *
 *  294 **  0.65167E+02 *  0.55131E+02 *  0.45741E+02 **  0.10475E+02 *  0.84856E+01 *  0.22416E+01 **  0.96843E+00 *
 *  295 **  0.40842E+02 *  0.19437E+02 *  0.63653E+02 **  0.72079E+01 *  0.22292E+01 *  0.79040E+01 **  0.91236E+00 *
 *      **               *               *              **               *               *              **               *
***************************************************************************************************************************
00:53:59  T=45.286  RC=0
```

RAW DATA FOR SUBJECT 2.

```
*****************************************
*                                       *
*   CALCULATED X.Y.Z COORDINATES        *
*  THEIR STANDARD ERROR OF ESTIMATE     *
*     AND PROBABILITY FACTOR            *
*                                       *
*****************************************

*************************************************************************************************************************
*     **                 *                *                **               *               *               **              *
* NUM **      X          *       Y        *       Z        **      SX       *      SY       *      SZ       **   PROBA.     *
*     **                 *                *                **               *               *               **              *
*************************************************************************************************************************
*     **                 *                *                **               *               *               **              *
*   1 ** 0.51556E+02 *-0.16514E+01 * 0.65805E+01 ** 0.44503E+01 * 0.60317E+00 * 0.34816E+01 ** 0.13049E+00 *
*   2 ** 0.20541E+02 * 0.52705E+01 * 0.23342E+02 ** 0.40863E+01 * 0.77466E+00 * 0.29735E+01 ** 0.61835E-02 *
*   3 ** 0.24712E+02 * 0.27757E+02 * 0.29654E+02 ** 0.34654E+01 * 0.21340E+01 * 0.20727E+01 ** 0.25164E+03 *
*   4 ** 0.29975E+02 * 0.50529E+02 * 0.22850E+02 ** 0.54319E+01 * 0.57602E+01 * 0.32656E+01 ** 0.51976E+00 *
*   5 ** 0.48641E+02 * 0.30295E+00 * 0.10441E+02 ** 0.61781E+01 * 0.65666E+00 * 0.45577E+01 ** 0.12859E+03 *
*   6 ** 0.56042E+02 *-0.71075E+00 * 0.11900E+02 ** 0.74402E+01 * 0.67750E+00 * 0.56737E+01 ** 0.77070E+00 *
*   7 ** 0.22421E+02 * 0.66557E+01 * 0.25137E+02 ** 0.40201E+01 * 0.86036E+00 * 0.32584E+01 ** 0.20326E-01 *
*   8 ** 0.27171E+02 * 0.21957E+02 * 0.31113E+02 ** 0.43860E+01 * 0.22864E+01 * 0.33404E+01 ** 0.21590E+00 *
*   9 ** 0.41515E+02 * 0.51236E+02 * 0.22279E+02 ** 0.55915E+01 * 0.53626E+01 * 0.31167E+01 ** 0.62104E+00 *
*  10 ** 0.53019E+02 * 0.23636E+01 * 0.14255E+02 ** 0.41259E+01 * 0.98750E+00 * 0.58046E+01 ** 0.34480E+00 *
*  11 ** 0.46657E+02 *-0.11156E+01 * 0.46394E+01 ** 0.40911E+01 * 0.50174E+00 * 0.44818E+01 ** 0.13721E-01 *
*  12 ** 0.44332E+01 * 0.42976E+01 * 0.30229E+02 ** 0.49403E+01 * 0.76062E+00 * 0.28405E+01 ** 0.25563E-02 *
*  13 ** 0.27034E+02 * 0.23956E+02 * 0.32378E+02 ** 0.44170E+01 * 0.22875E+01 * 0.24566E+01 ** 0.25531E+00 *
*  14 ** 0.39570E+02 * 0.51277E+02 * 0.24942E+02 ** 0.55555E+01 * 0.59631E+01 * 0.35174E+01 ** 0.56292E+00 *
*  15 ** 0.45317E+02 * 0.11947E+01 * 0.17672E+02 ** 0.10597E+02 * 0.72491E+00 * 0.56274E+01 ** 0.82237E-02 *
*  16 **-0.79115E+02 * 0.16027E+01 * 0.56444E+02 ** 0.62491E+02 * 0.17953E+01 * 0.24014E+02 ** 0.41334E-02 *
*  17 ** 0.75030E+01 * 0.52211E+01 * 0.30707E+02 ** 0.41430E+01 * 0.78315E+00 * 0.26873E+01 ** 0.14042E-02 *
*  18 ** 0.30653E+02 * 0.29740E+02 * 0.32928E+02 ** 0.49732E+01 * 0.26141E+01 * 0.37594E+01 ** 0.35107E+00 *
*  19 ** 0.42876E+02 * 0.51492E+02 * 0.24634E+02 ** 0.60637E+01 * 0.62837E+01 * 0.36528E+01 ** 0.60545E+00 *
*  20 ** 0.27017E+02 * 0.21312E+01 * 0.23154E+02 ** 0.11772E+02 * 0.69191E+00 * 0.40024E+01 ** 0.20952E-02 *
*  21 **-0.40276E+02 * 0.23856E+01 * 0.43042E+02 ** 0.35019E+02 * 0.11096E+01 * 0.15072E+02 ** 0.14052E-02 *
*  22 ** 0.20552E+02 * 0.79107E+01 * 0.20683E+02 ** 0.87831E+01 * 0.94819E+00 * 0.35157E+01 ** 0.12660E-01 *
*  23 **  0.34147E+02 * 0.25632E+02 * 0.31584E+02 ** 0.55526E+01 * 0.28172E+01 * 0.35631E+01 ** 0.32222E+00 *
*  24 **  0.43504E+02 * 0.52425E+02 * 0.25195E+02 ** 0.67194E+01 * 0.64911E+01 * 0.37599E+01 ** 0.61183E+00 *
*  25 ** -0.20280E+02 * 0.27092E+01 * 0.33544E+02 ** 0.17356E+02 * 0.64078E+00 * 0.67659E+01 ** 0.41258E-03 *
*  26 **  0.13925E+02 * 0.13800E+01 * 0.29475E+02 ** 0.16230E+02 * 0.71536E+00 * 0.39509E+01 ** 0.11694E-01 *
*  27 **  0.37642E+02 * 0.11019E+02 * 0.25143E+02 ** 0.99610E+01 * 0.18242E+01 * 0.46500E+01 ** 0.13360E+00 *
*  28 **  0.30327E+02 * 0.24223E+02 * 0.34609E+02 ** 0.51767E+01 * 0.25002E+01 * 0.39987E+01 ** 0.23260E+00 *
*  29 **  0.44466E+02 * 0.53027E+02 * 0.24776E+02 ** 0.63579E+01 * 0.66718E+01 * 0.37719E+01 ** 0.65054E+00 *
*  30 **  0.13531E+02 * 0.43430E+01 * 0.26253E+02 ** 0.11515E+02 * 0.73465E+00 * 0.30130E+01 ** 0.20854E-02 *
*  31 **  0.10710E+02 * 0.49101E+01 * 0.29240E+02 ** 0.12497E+02 * 0.75470E+00 * 0.32100E+01 ** 0.32087E-02 *
*  32 **  0.28453E+02 * 0.10442E+02 * 0.31906E+02 ** 0.88517E+01 * 0.12240E+01 * 0.41063E+01 ** 0.37151E-01 *
*  33 **  0.13028E+02 * 0.25073E+02 * 0.35639E+02 ** 0.56989E+01 * 0.27306E+01 * 0.43286E+01 ** 0.25776E+00 *
*  34 **  0.43263E+02 * 0.52940E+02 * 0.25966E+02 ** 0.62430E+01 * 0.65195E+01 * 0.38386E+01 ** 0.55237E+00 *
*  35 **  0.15709E+02 * 0.57021E+01 * 0.28666E+02 ** 0.10499E+02 * 0.80537E+00 * 0.31556E+01 ** 0.31029E-02 *
*  36 **  0.99059E+00 * 0.47547E+01 * 0.32296E+02 ** 0.13332E+02 * 0.76278E+00 * 0.36965E+01 ** 0.17276E-02 *
*  37 **  0.29218E+02 * 0.11195E+02 * 0.32595E+02 ** 0.67551E+01 * 0.13060E+01 * 0.42337E+01 ** 0.34061E-01 *
*  38 **  0.37558E+02 * 0.27116E+02 * 0.35442E+02 ** 0.64384E+01 * 0.32165E+01 * 0.46939E+01 ** 0.32624E+00 *
*  39 **  0.45686E+02 * 0.56321E+02 * 0.24409E+02 ** 0.65563E+01 * 0.70585E+01 * 0.37934E+01 ** 0.65950E+00 *
*  40 **  0.18287E+02 * 0.67604E+01 * 0.28737E+02 ** 0.98826E+01 * 0.87656E+00 * 0.31340E+01 ** 0.20056E-02 *
*  41 **  0.29858E+02 * 0.97492E+01 * 0.31054E+02 ** 0.10577E+02 * 0.12057E+01 * 0.42947E+01 ** 0.12678E-01 *
*  42 **  0.35819E+02 * 0.14174E+02 * 0.34123E+02 ** 0.84339E+01 * 0.17324E+01 * 0.40178E+01 ** 0.52995E-01 *
*  43 **  0.38951E+02 * 0.27666E+02 * 0.35991E+02 ** 0.67514E+01 * 0.33717E+01 * 0.48856E+01 ** 0.26838E+00 *
*  44 **  0.45748E+02 * 0.55715E+02 * 0.25195E+02 ** 0.56813E+01 * 0.70619E+01 * 0.38760E+01 ** 0.52692E+00 *
*  45 **  0.29088E+02 * 0.10144E+02 * 0.31532E+02 ** 0.90729E+01 * 0.12222E+01 * 0.41145E+01 ** 0.12650E-01 *
*  46 **  0.22134E+02 * 0.91910E+01 * 0.34122E+02 ** 0.96980E+01 * 0.10625E+01 * 0.39720E+01 ** 0.66379E-02 *
*  47 **  0.26187E+02 * 0.12034E+02 * 0.34047E+02 ** 0.77804E+01 * 0.13130E+01 * 0.39936E+01 ** 0.15689E-01 *
*  48 **  0.40205E+02 * 0.28919E+02 * 0.36585E+02 ** 0.69702E+01 * 0.36058E+01 * 0.50343E+01 ** 0.30129E+00 *
*  49 **  0.47251E+02 * 0.57735E+02 * 0.24402E+02 ** 0.68890E+01 * 0.73935E+01 * 0.38807E+01 ** 0.61195E+00 *
*  50 **  0.32567E+02 * 0.11872E+02 * 0.34141E+02 ** 0.99543E+01 * 0.14417E+01 * 0.46142E+01 ** 0.21423E-01 *
*  51 **  0.33349E+02 * 0.12616E+02 * 0.33609E+02 ** 0.95863E+01 * 0.15348E+01 * 0.45030E+01 ** 0.12177E-01 *
*  52 **  0.45884E+02 * 0.18691E+02 * 0.32751E+02 ** 0.99204E+01 * 0.25858E+01 * 0.52536E+01 ** 0.85579E-01 *
*  53 **  0.38952E+02 * 0.29355E+02 * 0.38782E+02 ** 0.68633E+01 * 0.36181E+01 * 0.52023E+01 ** 0.21624E+00 *
*  54 **  0.46329E+02 * 0.57144E+02 * 0.25775E+02 ** 0.60403E+01 * 0.73450E+01 * 0.39690E+01 ** 0.53214E+00 *
*  55 **  0.47006E+02 * 0.17239E+02 * 0.33529E+02 ** 0.10841E+02 * 0.24540E+01 * 0.52477E+01 ** 0.50728E-01 *
*  56 **  0.54735E+02 * 0.20433E+02 * 0.33605E+02 ** 0.12149E+02 * 0.31913E+01 * 0.57890E+01 ** 0.52100E-01 *
*  57 **  0.54541E+02 * 0.23959E+02 * 0.35354E+02 ** 0.11351E+02 * 0.37250E+01 * 0.60943E+01 ** 0.15097E+00 *
*  58 **  0.43542E+02 * 0.32141E+02 * 0.35168E+02 ** 0.76321E+01 * 0.43135E+01 * 0.57109E+01 ** 0.31266E+00 *
*  59 **  0.47423E+02 * 0.58679E+02 * 0.25054E+02 ** 0.69727E+01 * 0.75884E+01 * 0.39747E+01 ** 0.60842E+00 *
*  60 **  0.56983E+02 * 0.21933E+02 * 0.35290E+02 ** 0.12613E+02 * 0.35130E+01 * 0.62023E+01 ** 0.49476E-01 *
*  61 **  0.59246E+02 * 0.24165E+02 * 0.36207E+02 ** 0.13066E+02 * 0.40173E+01 * 0.65442E+01 ** 0.84523E-01 *
*  62 **  0.57763E+02 * 0.27742E+02 * 0.36693E+02 ** 0.11912E+02 * 0.45101E+01 * 0.65127E+01 ** 0.16205E+00 *
*  63 **  0.43427E+02 * 0.34209E+02 * 0.41462E+02 ** 0.77423E+01 * 0.45851E+01 * 0.59742E+01 ** 0.26375E+00 *
*  64 **  0.44940E+02 * 0.57198E+02 * 0.27917E+02 ** 0.67147E+01 * 0.71571E+01 * 0.41820E+01 ** 0.50674E+00 *
*  65 **  0.64731E+02 * 0.27821E+02 * 0.34771E+02 ** 0.13639E+02 * 0.47956E+01 * 0.65071E+01 ** 0.11831E+00 *
*  66 **  0.65150E+02 * 0.29763E+02 * 0.33271E+02 ** 0.13850E+02 * 0.51068E+01 * 0.67064E+01 ** 0.67556E-01 *
*  67 **  0.68065E+02 * 0.30560E+02 * 0.36357E+02 ** 0.11718E+02 * 0.49628E+01 * 0.64165E+01 ** 0.13011E+00 *
*  68 **  0.46555E+02 * 0.36286E+02 * 0.42153E+02 ** 0.85612E+01 * 0.51615E+01 * 0.64229E+01 ** 0.27390E+00 *
*  69 **  0.47614E+02 * 0.60994E+02 * 0.25336E+02 ** 0.70401E+01 * 0.79651E+01 * 0.40215E+01 ** 0.59175E+00 *
*  70 **  0.71457E+02 * 0.31672E+02 * 0.30657E+02 ** 0.14840E+02 * 0.56107E+01 * 0.61676E+01 ** 0.93666E-01 *
*  71 **  0.82394E+02 * 0.39105E+02 * 0.32136E+02 ** 0.17915E+02 * 0.76261E+01 * 0.71092E+01 ** 0.14543E+00 *
*  72 **  0.68086E+02 * 0.37871E+02 * 0.35590E+02 ** 0.14321E+02 * 0.68661E+01 * 0.70584E+01 ** 0.20370E+00 *
*  73 **  0.44356E+02 * 0.38525E+02 * 0.43609E+02 ** 0.78410E+01 * 0.52716E+01 * 0.62764E+01 ** 0.26203E+00 *
*  74 **  0.48139E+02 * 0.60150E+02 * 0.25424E+02 ** 0.72243E+01 * 0.79294E+01 * 0.40984E+01 ** 0.50403E+00 *
*  75 **  0.89544E+02 * 0.41139E+02 * 0.31303E+02 ** 0.19393E+02 * 0.86304E+01 * 0.74411E+01 ** 0.31647E+00 *
*  76 **  0.93659E+02 * 0.47975E+02 * 0.28970E+02 ** 0.19911E+02 * 0.94841E+01 * 0.70174E+01 ** 0.20658E+00 *
*  77 **  0.69853E+02 * 0.42134E+02 * 0.35928E+02 ** 0.14459E+02 * 0.77628E+01 * 0.71748E+01 ** 0.21356E+00 *
*  78 **  0.50719E+02 * 0.42359E+02 * 0.41943E+02 ** 0.92504E+01 * 0.63846E+01 * 0.67402E+01 ** 0.29158E+00 *
*  79 **  0.48674E+02 * 0.60713E+02 * 0.25554E+02 ** 0.73053E+01 * 0.80324E+01 * 0.40948E+01 ** 0.52086E+00 *
*  80 **  0.87259E+02 * 0.46311E+02 * 0.32831E+02 ** 0.17144E+02 * 0.91660E+01 * 0.76035E+01 ** 0.25573E+00 *
*  81 **  0.87318E+02 * 0.49551E+02 * 0.31560E+02 ** 0.19031E+02 * 0.93375E+01 * 0.72023E+01 ** 0.11372E+00 *
*  82 **  0.70869E+02 * 0.45851E+02 * 0.30453E+02 ** 0.14712E+02 * 0.85100E+01 * 0.73157E+01 ** 0.20141E+00 *
*  83 ** 0.50453E+02 * 0.46180E+02 * 0.44037E+02 ** 0.91852E+01 * 0.65983E+01 * 0.70637E+01 ** 0.31408E+00 *
*  84 ** 0.49460E+02 * 0.42920E+02 * 0.23306E+02 ** 0.72392E+01 * 0.81819E+01 * 0.38471E+01 ** 0.52890E+00 *
*  85 ** 0.84254E+02 * 0.44755E+02 * 0.13429E+02 ** 0.18421E+02 * 0.97700E+01 * 0.74547E+01 ** 0.18869E+00 *
*  86 ** 0.99255E+02 * 0.54563E+02 * 0.32083E+02 ** 0.22440E+02 * 0.12488E+02 * 0.80510E+01 ** 0.27106E+00 *
*  87 ** 0.79746E+02 * 0.54267E+02 * 0.38107E+02 ** 0.17582E+02 * 0.11028E+02 * 0.83681E+01 ** 0.27616E+00 *
*  88 ** 0.52519E+02 * 0.50478E+02 * 0.44617E+02 ** 0.36592E+01 * 0.78907E+01 * 0.73588E+01 ** 0.32476E+00 *
*  89 ** 0.49051E+02 * 0.45164E+02 * 0.24067E+02 ** 0.72920E+01 * 0.85010E+01 * 0.40076E+01 ** 0.56152E+00 *
*  90 ** 0.92393E+02 * 0.57667E+02 * 0.33528E+02 ** 0.20700E+02 * 0.12110E+02 * 0.80414E+01 ** 0.26098E+00 *
*  91 ** 0.10163E+03 * 0.68355E+02 * 0.40731E+02 ** 0.22231E+02 * 0.14170E+02 * 0.78514E+01 ** 0.30485E+00 *
*  92 ** 0.80807E+02 * 0.61740E+02 * 0.37561E+02 ** 0.17659E+02 * 0.12472E+02 * 0.83394E+01 ** 0.34429E+00 *
*  93 ** 0.55764E+02 * 0.56233E+02 * 0.44493E+02 ** 0.10455E+02 * 0.92029E+01 * 0.70832E+01 ** 0.36084E+00 *
*  94 ** 0.52550E+02 * 0.63947E+02 * 0.23173E+02 ** 0.78818E+01 * 0.89032E+01 * 0.40813E+01 ** 0.61065E+00 *
*  95 ** 0.94554E+02 * 0.65439E+02 * 0.33158E+02 ** 0.21107E+02 * 0.13826E+02 * 0.81041E+01 ** 0.34407E+00 *
*  96 ** 0.95240E+02 * 0.71194E+02 * 0.35070E+02 ** 0.21904E+02 * 0.15508E+02 * 0.86064E+01 ** 0.31214E+00 *
*  97 ** 0.78431E+02 * 0.64177E+02 * 0.40563E+02 ** 0.17243E+02 * 0.13132E+02 * 0.88895E+01 ** 0.34145E+00 *
*  98 ** 0.56596E+02 * 0.60664E+02 * 0.45560E+02 ** 0.10677E+02 * 0.10084E+02 * 0.79743E+01 ** 0.39433E+00 *
*  99 ** 0.51475E+02 * 0.62291E+02 * 0.22680E+02 ** 0.75380E+01 * 0.87309E+01 * 0.38935E+01 ** 0.61169E+00 *
* 100 ** 0.87231E+02 * 0.67322E+02 * 0.41450E+02 ** 0.20463E+02 * 0.14815E+02 * 0.94017E+01 ** 0.32357E+00 *
* 101 ** 0.89355E+02 * 0.72608E+02 * 0.41421E+02 ** 0.21214E+02 * 0.16258E+02 * 0.95483E+01 ** 0.35162E+00 *
* 102 ** 0.86849E+02 * 0.71754E+02 * 0.40717E+02 ** 0.18027E+02 * 0.14909E+02 * 0.91402E+01 ** 0.35552E+00 *
* 103 ** 0.57320E+02 * 0.66714E+02 * 0.42495E+02 ** 0.10664E+02 * 0.11080E+02 * 0.74550E+01 ** 0.42103E+00 *
* 104 ** 0.54484E+02 * 0.65981E+02 * 0.19362E+02 ** 0.75475E+01 * 0.84030E+01 * 0.36643E+01 ** 0.78175E+00 *
* 105 ** 0.87701E+02 * 0.72327E+02 * 0.40678E+02 ** 0.20473E+02 * 0.15909E+02 * 0.56303E+01 ** 0.35364E+00 *
* 106 ** 0.83708E+02 * 0.76650E+02 * 0.40118E+02 ** 0.21067E+02 * 0.17477E+02 * 0.96274E+01 ** 0.35654E+00 *
* 107 ** 0.77007E+02 * 0.74890E+02 * 0.40637E+02 ** 0.16622E+02 * 0.15998E+02 * 0.86784E+01 ** 0.35281E+00 *
* 108 ** 0.59104E+02 * 0.71782E+02 * 0.40899E+02 ** 0.11064E+02 * 0.12132E+02 * 0.72983E+01 ** 0.46092E+00 *
* 109 ** 0.55131E+02 * 0.65935E+02 * 0.18177E+02 ** 0.74288E+01 * 0.82198E+01 * 0.35669E+01 ** 0.82450E+00 *
* 110 ** 0.96016E+02 * 0.81818E+02 * 0.37038E+02 ** 0.22449E+02 * 0.18288E+02 * 0.52805E+01 ** 0.46391E+00 *
* 111 ** 0.88984E+02 * 0.84189E+02 * 0.40825E+02 ** 0.20837E+02 * 0.18738E+02 * 0.57934E+01 ** 0.36737E+00 *
* 112 ** 0.74581E+02 * 0.80208E+02 * 0.41362E+02 ** 0.15935E+02 * 0.15998E+02 * 0.88131E+01 ** 0.41452E+00 *
* 113 ** 0.59010E+02 * 0.77077E+02 * 0.41712E+02 ** 0.11012E+02 * 0.13061E+02 * 0.75601E+01 ** 0.53950E+00 *
* 114 ** 0.58582E+02 * 0.64349E+02 * 0.16228E+02 ** 0.76835E+01 * 0.78334E+01 * 0.35149E+01 ** 0.77573E+00 *
* 115 ** 0.88564E+02 * 0.83556E+02 * 0.40664E+02 ** 0.20544E+02 * 0.18493E+02 * 0.97413E+01 ** 0.43955E+00 *
* 116 ** 0.85038E+02 * 0.87148E+02 * 0.30767E+02 ** 0.19165E+02 * 0.18567E+02 * 0.85013E+01 ** 0.36648E+00 *
* 117 ** 0.76430E+02 * 0.87528E+02 * 0.38103E+02 ** 0.16077E+02 * 0.17328E+02 * 0.82453E+01 ** 0.45244E+00 *
* 118 ** 0.59320E+02 * 0.83318E+02 * 0.41319E+02 ** 0.10990E+02 * 0.14102E+02 * 0.75266E+01 ** 0.63923E+00 *
* 119 ** 0.56086E+02 * 0.63950E+02 * 0.16183E+02 ** 0.77859E+01 * 0.80565E+01 * 0.36168E+01 ** 0.70765E+00 *
* 120 ** 0.86356E+02 * 0.89678E+02 * 0.36783E+02 ** 0.19171E+02 * 0.18685E+02 * 0.85822E+01 ** 0.42616E+00 *
* 121 ** 0.75622E+02 * 0.99860E+02 * 0.40528E+02 ** 0.16154E+02 * 0.19882E+02 * 0.87710E+01 ** 0.47528E+00 *
* 122 ** 0.39462E+01 * 0.91584E+02 * 0.44320E+02 ** 0.23141E+01 * 0.62883E+01 * 0.35627E+01 ** 0.72139E+00 *
* 123 ** 0.53558E+02 * 0.85746E+02 * 0.31279E+02 ** 0.92615E+01 * 0.13372E+02 * 0.65192E+01 ** 0.66697E+00 *
* 124 ** 0.60141E+02 * 0.61846E+02 * 0.18190E+02 ** 0.53191E+01 * 0.79971E+01 * 0.37913E+01 ** 0.80756E+00 *
* 125 ** 0.74653E+02 * 0.98827E+02 * 0.41748E+02 ** 0.15988E+02 * 0.19034E+02 * 0.89726E+01 ** 0.48908E+00 *
* 126 ** 0.69359E+02 * 0.10262E+03 * 0.41812E+02 ** 0.14270E+02 * 0.19691E+02 * 0.85467E+01 ** 0.53256E+00 *
* 127 ** 0.61223E+02 * 0.93676E+02 * 0.39510E+02 ** 0.11524E+02 * 0.16243E+02 * 0.73346E+01 ** 0.54797E+00 *
* 128 ** 0.52135E+02 * 0.83342E+02 * 0.21299E+02 ** 0.84787E+01 * 0.12221E+02 * 0.52307E+01 ** 0.65814E+00 *
* 129 ** 0.61629E+02 * 0.62172E+02 * 0.17574E+02 ** 0.94580E+01 * 0.79421E+01 * 0.37781E+01 ** 0.76465E+00 *
* 130 ** 0.68524E+02 * 0.97967E+02 * 0.41531E+02 ** 0.14915E+02 * 0.18563E+02 * 0.84311E+01 ** 0.53156E+00 *
* 131 ** 0.61449E+02 * 0.10672E+03 * 0.40751E+02 ** 0.11706E+02 * 0.18783E+02 * 0.77153E+01 ** 0.58698E+00 *
* 132 ** 0.56774E+02 * [illegible] * 0.38072E+02 ** 0.13010E+02 * 0.15539E+02 * 0.63971E+01 ** 0.60510E+00 *
* 133 ** 0.50288E+02 * 0.61419E+02 * 0.26000E+02 ** 0.76320E+01 * 0.11122E+02 * 0.45381E+01 ** 0.69136E+00 *
* 134 ** 0.61412E+02 * 0.62233E+02 * 0.18235E+02 ** 0.86122E+01 * 0.81248E+01 * 0.38205E+01 ** 0.65012E+00 *
* 135 ** 0.62278E+02 * 0.10172E+03 * 0.40348E+02 ** 0.11930E+02 * 0.17909E+02 * 0.71659E+01 ** 0.56595E+00 *
* 136 ** 0.53974E+02 * 0.10759E+03 * 0.40756E+02 ** 0.95667E+01 * 0.17292E+02 * 0.70505E+01 ** 0.63847E+00 *
* 137 ** 0.53173E+02 * 0.97800E+02 * 0.24210E+02 ** 0.89576E+01 * 0.14946E+02 * 0.58450E+01 ** 0.66745E+00 *
* 138 ** 0.51473E+02 * 0.82498E+02 * 0.23309E+02 ** 0.75630E+01 * 0.11041E+02 * 0.40806E+01 ** 0.80425E+00 *
* 139 ** 0.64513E+02 * 0.60803E+02 * 0.15768E+02 ** 0.14806E+01 * 0.75348E+01 * 0.36477E+01 ** 0.71420E+00 *
* 140 ** 0.45256E+02 * 0.10288E+03 * 0.39201E+02 ** 0.94212E+01 * 0.16631E+02 * 0.68921E+01 ** 0.62193E+00 *
* 141 ** 0.47252E+02 * 0.11054E+03 * 0.37027E+02 ** 0.77532E+01 * 0.16099E+02 * 0.55205E+01 ** 0.72157E+00 *
* 142 ** 0.47929E+02 * 0.99290E+02 * 0.34326E+02 ** 0.76925E+01 * 0.14215E+02 * 0.55024E+01 ** 0.77615E+00 *
```

THE UNIVERSITY OF ALBERTA

```
*  143 ** 0.50891E+02 * 0.81425E+02 * 0.22141E+02 ** 0.93271E+01 * 0.10612E+02 * 0.39219E+01 ** 0.93061E+00 *
*  144 ** 0.65110E+02 * 0.58359E+02 * 0.16427E+02 ** 0.47884E+01 * 0.74058E+01 * 0.37848E+01 ** 0.66063E+00 *
*  145 ** 0.49238E+02 * 0.10688E+03 * 0.27428E+02 ** 0.82975E+01 * 0.16008E+02 * 0.61426E+01 ** 0.70997E+00 *
*  146 ** 0.40475E+02 * 0.11157E+03 * 0.35140E+02 ** 0.51653E+01 * 0.14604E+02 * 0.51631E+01 ** 0.86182E+00 *
*  147 ** 0.43088E+02 * 0.97594E+02 * 0.32455E+02 ** 0.65598E+01 * 0.12967E+02 * 0.56197E+01 ** 0.64865E+00 *
*  148 ** 0.51603E+02 * 0.77793E+02 * 0.21729E+02 ** 0.72760E+01 * 0.10103E+02 * 0.38924E+01 ** 0.94139E+00 *
*  149 ** 0.60574E+02 * 0.55719E+02 * 0.22175E+02 ** 0.94269E+01 * 0.78954E+01 * 0.42213E+01 ** 0.43337E+00 *
*  150 ** 0.40854E+02 * 0.10635E+03 * 0.35297E+02 ** 0.63655E+01 * 0.14147E+02 * 0.51473E+01 ** 0.77054E+00 *
*  151 ** 0.34284E+02 * 0.11294E+03 * 0.30740E+02 ** 0.48624E+01 * 0.13177E+02 * 0.41584E+01 ** 0.92483E+00 *
*  152 ** 0.38979E+02 * 0.96653E+02 * 0.29270E+02 ** 0.55377E+01 * 0.11807E+02 * 0.41997E+01 ** 0.94028E+00 *
*  153 ** 0.58616E+02 * 0.73950E+02 * 0.16920E+02 ** 0.60711E+01 * 0.85001E+01 * 0.21888E+01 ** 0.36371E+00 *
*  154 ** 0.62971E+02 * 0.54401E+02 * 0.21994E+02 ** 0.99083E+01 * 0.78240E+01 * 0.43067E+01 ** 0.41972E+00 *
*  155 ** 0.36116E+02 * 0.10810E+03 * 0.33902E+02 ** 0.52539E+01 * 0.13072E+02 * 0.46354E+01 ** 0.50370E+00 *
*  156 ** 0.27128E+02 * 0.10987E+03 * 0.27687E+02 ** 0.36522E+01 * 0.11130E+02 * 0.33722E+01 ** 0.95034E+00 *
*  157 ** 0.34652E+02 * 0.92843E+02 * 0.26527E+02 ** 0.46204E+01 * 0.10318E+02 * 0.36034E+01 ** 0.95307E+00 *
*  158 ** 0.48765E+02 * 0.69215E+02 * 0.15104E+02 ** 0.57586E+01 * 0.75901E+01 * 0.30080E+01 ** 0.98283E+00 *
*  159 ** 0.69744E+02 * 0.55763E+02 * 0.19617E+02 ** 0.10573E+02 * 0.79415E+01 * 0.43722E+01 ** 0.63232E+00 *
*  160 ** 0.28553E+02 * 0.10536E+03 * 0.31485E+02 ** 0.34849E+01 * 0.11091E+02 * 0.30275E+01 ** 0.97377E+00 *
*  161 ** 0.22132E+02 * 0.10424E+03 * 0.26237E+02 ** 0.29749E+01 * 0.94634E+01 * 0.29227E+01 ** 0.99999E+00 *
*  162 ** 0.31597E+02 * 0.86294E+02 * 0.25152E+02 ** 0.41282E+01 * 0.90206E+01 * 0.33066E+01 ** 0.55790E+00 *
*  163 ** 0.47609E+02 * 0.64057E+02 * 0.18121E+02 ** 0.60810E+01 * 0.74409E+01 * 0.32294E+01 ** 0.53309E+00 *
*  164 ** 0.71566E+02 * 0.53640E+02 * 0.21978E+02 ** 0.11648E+02 * 0.81621E+01 * 0.47767E+01 ** 0.56604E+00 *
*  165 ** 0.24063E+02 * 0.10031E+03 * 0.26904E+02 ** 0.32407E+01 * 0.94410E+01 * 0.32345E+01 ** 0.95987E+00 *
*  166 ** 0.16227E+02 * 0.97184E+02 * 0.22017E+02 ** 0.22857E+01 * 0.76140E+01 * 0.22707E+01 ** 0.92140E+00 *
*  167 ** 0.20497E+02 * 0.78969E+02 * 0.22626E+02 ** 0.37313E+01 * 0.77747E+01 * 0.29196E+01 ** 0.94492E+00 *
*  168 ** 0.50993E+02 * 0.58650E+02 * 0.17618E+02 ** 0.65423E+01 * 0.69836E+01 * 0.32744E+01 ** 0.96376E+00 *
*  169 ** 0.66146E+02 * 0.49794E+02 * 0.25413E+02 ** 0.11356E+02 * 0.77910E+01 * 0.44827E+01 ** 0.37923E+00 *
*  170 ** 0.21644E+02 * 0.93096E+02 * 0.24852E+02 ** 0.28417E+01 * 0.81069E+01 * 0.27200E+01 ** 0.47309E+00 *
*  171 ** 0.15519E+02 * 0.82630E+02 * 0.17744E+02 ** 0.20295E+01 * 0.59931E+01 * 0.18642E+01 ** 0.57769E+00 *
*  172 ** 0.32865E+02 * 0.67192E+02 * 0.18456E+02 ** 0.37399E+01 * 0.65363E+01 * 0.21323E+01 ** 0.88371E+00 *
*  173 ** 0.51684E+02 * 0.51895E+02 * 0.17775E+02 ** 0.67157E+01 * 0.62074E+01 * 0.33492E+01 ** 0.95751E+00 *
*  174 ** 0.67559E+02 * 0.49314E+02 * 0.27099E+02 ** 0.12034E+02 * 0.79948E+01 * 0.53404E+01 ** 0.36788E+00 *
*  175 ** 0.21223E+02 * 0.80499E+02 * 0.22039E+02 ** 0.26279E+01 * 0.66728E+01 * 0.22905E+01 ** 0.81048E+00 *
*  176 ** 0.17248E+02 * 0.57931E+02 * 0.13276E+02 ** 0.19673E+01 * 0.39646E+01 * 0.15377E+01 ** 0.45641E+00 *
*  177 ** 0.33262E+02 * 0.49135E+02 * 0.17286E+02 ** 0.37655E+01 * 0.46750E+01 * 0.24704E+01 ** 0.95583E+00 *
*  178 ** 0.63219E+02 * 0.42378E+02 * 0.20627E+02 ** 0.75279E+01 * 0.53822E+01 * 0.39599E+01 ** 0.70522E+00 *
*  179 ** 0.75257E+02 * 0.52792E+02 * 0.26252E+02 ** 0.13585E+02 * 0.89165E+01 * 0.56927E+01 ** 0.54122E+00 *
*  180 ** 0.22395E+02 * 0.57332E+02 * 0.17385E+02 ** 0.24832E+01 * 0.45119E+01 * 0.19953E+01 ** 0.81174E+00 *
*  181 ** 0.22521E+02 * 0.41433E+02 * 0.13466E+02 ** 0.22561E+01 * 0.31186E+01 * 0.10969E+01 ** 0.36194E+00 *
*  182 ** 0.41023E+02 * 0.37217E+02 * 0.16867E+02 ** 0.49211E+01 * 0.39266E+01 * 0.24309E+01 ** 0.55126E+00 *
*  183 ** 0.57660E+02 * 0.38625E+02 * 0.25139E+02 ** 0.92918E+01 * 0.55693E+01 * 0.46358E+01 ** 0.71951E+00 *
*  184 ** 0.75172E+02 * 0.52802E+02 * 0.28749E+02 ** 0.14138E+02 * 0.92621E+01 * 0.61629E+01 ** 0.56727E+00 *
*  185 ** 0.28637E+02 * 0.41714E+02 * 0.16034E+02 ** 0.30245E+01 * 0.36307E+01 * 0.21635E+01 ** 0.51820E+00 *
*  186 ** 0.24369E+02 * 0.18297E+02 * 0.79904E+01 ** 0.28613E+01 * 0.16695E+01 * 0.17961E+01 ** 0.14497E-02 *
*  187 ** 0.48012E+02 * 0.25652E+02 * 0.14057E+02 ** 0.55708E+01 * 0.28085E+01 * 0.29574E+01 ** 0.96191E+00 *
*  188 ** 0.62529E+02 * 0.32963E+02 * 0.23801E+02 ** 0.10397E+02 * 0.48822E+01 * 0.47034E+01 ** 0.57745E+00 *
*  189 ** 0.77694E+02 * 0.52017E+02 * 0.26798E+02 ** 0.19354E+02 * 0.90025E+01 * 0.55088E+01 ** 0.54863E+00 *
*  190 ** 0.38084E+02 * 0.26710E+02 * 0.15966E+02 ** 0.42402E+01 * 0.27315E+01 * 0.20234E+01 ** 0.45200E+00 *
*  191 ** 0.49703E+02 * 0.59772E+01 * 0.77278E+01 ** 0.49861E+01 * 0.12774E+01 * 0.30175E+01 ** 0.40144E-03 *
*  192 ** 0.62787E+02 * 0.14792E+02 * 0.11736E+02 ** 0.76334E+01 * 0.20215E+01 * 0.37729E+01 ** 0.76874E+00 *
*  193 ** 0.74244E+02 * 0.30555E+02 * 0.18898E+02 ** 0.11380E+02 * 0.44456E+01 * 0.47360E+01 ** 0.90004E+00 *
*  194 ** 0.79454E+02 * 0.52930E+02 * 0.27015E+02 ** 0.14874E+02 * 0.92975E+01 * 0.60457E+01 ** 0.53976E+00 *
*  195 ** 0.53221E+02 * 0.99519E+01 * 0.10601E+02 ** 0.60322E+01 * 0.15519E+01 * 0.33520E+01 ** 0.92500E-01 *

 FIT IS STOPPED AFTER TOO MANY CONSECUTIVE DIVERGENCES. = 11
*  196 ** 0.46770E+02 * 0.26673E+01 * 0.31100E+02 ** 0.10297E+02 * 0.11020E+01 * 0.61656E+01 ** 0.28327E-02 *
*  197 ** 0.74572E+02 * 0.85513E+01 * 0.12566E+02 ** 0.10751E+02 * 0.17771E+01 * 0.55149E+01 ** 0.97759E+00 *
*  198 ** 0.75660E+02 * 0.29813E+02 * 0.22186E+02 ** 0.13160E+02 * 0.47117E+01 * 0.51071E+01 ** 0.52262E+00 *
*  199 ** 0.60325E+02 * 0.51552E+02 * 0.26612E+02 ** 0.19967E+02 * 0.50408E+01 * 0.60901E+01 ** 0.53103E+00 *
```

THE UNIVERSITY OF ALBERTA

```
 FIT IS STOPPED AFTER TOO MANY CONSECUTIVE DIVERGENCES. = 11
*  200 ** 0.78858E+02 * 0.51583E+01 * 0.30747E+02 ** 0.19302E+02 * 0.19681E+01 * 0.10342E+02 ** 0.21601E-02 *
*  201 ** 0.66506E+02 *-0.52706E+01 * 0.31203E+02 ** 0.16567E+02 * 0.13552E+01 * 0.72321E+01 ** 0.17384E+00 *
*  202 ** 0.68005E+02 * 0.48507E+01 * 0.26513E+02 ** 0.20480E+02 * 0.13663E+01 * 0.10158E+02 ** 0.33741E+00 *
*  203 ** 0.62452E+02 * 0.26708E+02 * 0.22163E+02 ** 0.18808E+02 * 0.88255E+01 * 0.57181E+01 ** 0.66565E+00 *
*  204 ** 0.60166E+02 * 0.53037E+02 * 0.26184E+02 ** 0.14942E+02 * 0.92593E+01 * 0.58708E+01 ** 0.57450E+00 *
*  205 ** 0.65983E+02 *-0.49520E+01 * 0.27482E+02 ** 0.19495E+02 * 0.12600E+01 * 0.56048E+01 ** 0.72562E+00 *
*  206 ** 0.10752E+03 *-0.97894E+01 * 0.14152E+02 ** 0.15466E+02 * 0.17426E+01 * 0.72584E+01 ** 0.95977E+00 *
*  207 **-0.19541E+02 * 0.26949E+01 * 0.46810E+02 ** 0.35982E+02 * 0.11158E+01 * 0.12666E+02 ** 0.31425E-01 *
*  208 ** 0.70640E+02 * 0.25409E+02 * 0.27088E+02 ** 0.14157E+02 * 0.43009E+01 * 0.58259E+01 ** 0.25166E+00 *
*  209 ** 0.60584E+02 * 0.53752E+02 * 0.26647E+02 ** 0.15065E+02 * 0.94587E+01 * 0.60401E+01 ** 0.54396E+00 *
*  210 ** 0.11147E+03 *-0.65786E+01 * 0.11139E+02 ** 0.14907E+02 * 0.13126E+01 * 0.82611E+01 ** 0.97104E+00 *
*  211 ** 0.25652E+03 * 0.28987E+01 *-0.10065E+03 ** 0.26209E+03 * 0.52176E+01 * 0.10543E+03 ** 0.72299E-01 *
*  212 **-0.11186E+03 * 0.47575E+01 * 0.94796E+02 ** 0.39923E+02 * 0.32830E+01 * 0.45511E+02 ** 0.50275E-01 *
*  213 ** 0.65291E+02 * 0.24721E+02 * 0.31699E+02 ** 0.13814E+02 * 0.42058E+01 * 0.61764E+01 ** 0.14767E+00 *
*  214 ** 0.81412E+02 * 0.54276E+02 * 0.29035E+02 ** 0.15999E+02 * 0.99855E+01 * 0.65163E+01 ** 0.46035E+00 *
*  215 ** 0.12199E+02 *-0.30581E+01 *-0.10993E+02 ** 0.17225E+02 * 0.11503E+01 * 0.81349E+01 ** 0.34863E+00 *
*  216 **-0.17471E+01 * 0.20841E+01 * 0.13316E+03 ** 0.13789E+03 * 0.33958E+01 * 0.82536E+02 ** 0.30128E-01 *
*  217 ** 0.73626E+01 * 0.78574E+01 * 0.46209E+02 ** 0.16647E+02 * 0.93760E+00 * 0.45562E+01 ** 0.22179E-01 *
*  218 ** 0.54371E+02 * 0.23816E+02 * 0.36549E+02 ** 0.11670E+02 * 0.36684E+01 * 0.62667E+01 ** 0.16869E+00 *
*  219 ** 0.80616E+02 * 0.54832E+02 * 0.30716E+02 ** 0.16193E+02 * 0.10285E+02 * 0.68179E+01 ** 0.44451E+00 *
*  220 ** 0.17370E+03 *-0.19551E+01 *-0.42598E+02 ** 0.71044E+02 * 0.18447E+01 * 0.31314E+02 ** 0.17419E+00 *
*  221 **-0.70555E+00 * 0.75767E+01 * 0.51165E+02 ** 0.16803E+02 * 0.97997E+00 * 0.57139E+01 ** 0.19327E-01 *
*  222 ** 0.26034E+02 * 0.11569E+02 * 0.46253E+02 ** 0.11360E+02 * 0.13341E+01 * 0.58213E+01 ** 0.36154E-01 *
*  223 ** 0.62541E+02 * 0.27101E+02 * 0.37921E+02 ** 0.13624E+02 * 0.46848E+01 * 0.71372E+01 ** 0.17381E+00 *
*  224 ** 0.83521E+02 * [illegible] * [illegible] ** 0.17241E+02 * 0.11266E+02 * 0.72136E+01 ** 0.45739E+00 *
*  225 **-0.53039E+04 * 0.11944E+03 * [illegible] ** 0.11855E+07 * 0.25372E+05 * [illegible] ** 0.14493E+00 *
*  226 ** 0.24807E+02 * 0.11378E+02 * 0.48418E+02 ** 0.13705E+02 * 0.13373E+01 * [illegible] ** [illegible] *
*  227 ** 0.10639E+03 * 0.29121E+02 * 0.39047E+02 ** 0.24929E+02 * 0.70452E+01 * 0.10941E+02 ** 0.30544E+00 *
*  228 ** 0.72101E+02 * 0.31865E+02 * 0.39760E+02 ** 0.16130E+02 * 0.61149E+01 * 0.82962E+01 ** 0.24890E+00 *
*  229 ** 0.80346E+02 * 0.58188E+02 * 0.36127E+02 ** 0.17260E+02 * 0.11617E+02 * 0.79825E+01 ** 0.37036E+00 *
*  230 **-0.68462E+02 * 0.68596E+01 * 0.50014E+02 ** 0.75664E+02 * 0.32783E+01 * 0.40287E+02 ** 0.25000E+00 *
*  231 ** 0.61322E+02 * 0.16171E+02 * 0.47818E+02 ** 0.19376E+02 * 0.32923E+01 * 0.94481E+01 ** 0.11364E+00 *
*  232 ** 0.89387E+02 * 0.25905E+02 * 0.44341E+02 ** 0.24922E+02 * 0.59227E+01 * 0.11104E+02 ** 0.27799E+00 *
*  233 ** 0.73626E+02 * 0.33756E+02 * 0.42601E+02 ** 0.17010E+02 * 0.60840E+01 * 0.91167E+01 ** 0.32059E+00 *
*  234 ** 0.85075E+02 * 0.61013E+02 * 0.37064E+02 ** 0.18816E+02 * 0.12690E+02 * 0.85336E+01 ** 0.38202E+00 *
*  235 ** 0.11292E+02 * 0.76046E+01 * 0.62076E+02 ** 0.38791E+02 * 0.13638E+01 * 0.11598E+02 ** 0.26118E+00 *
*  236 ** 0.73048E+02 * 0.23061E+02 * 0.50842E+02 ** 0.21478E+02 * 0.47645E+01 * 0.11184E+02 ** 0.16320E+00 *
*  237 ** 0.88067E+02 * 0.26121E+02 * 0.45003E+02 ** 0.26871E+02 * 0.65325E+01 * 0.12171E+02 ** 0.28258E+00 *
*  238 ** 0.76950E+02 * 0.37068E+02 * 0.46131E+02 ** 0.14361E+02 * 0.77048E+01 * 0.10224E+02 ** 0.34819E+00 *
*  239 ** 0.65364E+02 * 0.63224E+02 * 0.39014E+02 ** 0.19290E+02 * 0.13430E+02 * 0.90634E+01 ** 0.40115E+00 *
*  240 ** 0.73484E+01 * 0.11347E+02 * 0.67674E+02 ** 0.16066E+02 * 0.12186E+01 * 0.58855E+01 ** 0.81954E-01 *
*  241 ** 0.65737E+02 * 0.23959E+02 * 0.53904E+02 ** 0.20363E+02 * 0.48253E+01 * 0.11498E+02 ** 0.16805E+00 *
*  242 ** 0.90860E+02 * 0.31004E+02 * 0.51512E+02 ** 0.25887E+02 * 0.74513E+01 * 0.13136E+02 ** 0.30247E+00 *
*  243 ** 0.77316E+02 * 0.38258E+02 * 0.48802E+02 ** 0.18784E+02 * 0.80913E+01 * 0.10927E+02 ** 0.34054E+00 *
*  244 ** 0.67778E+02 * 0.66040E+02 * 0.39675E+02 ** 0.20193E+02 * 0.14347E+02 * 0.96201E+01 ** 0.46179E+00 *
*  245 ** 0.13103E+02 * 0.13027E+02 * 0.65270E+02 ** 0.15589E+02 * 0.13547E+01 * 0.73914E+01 ** 0.95339E-01 *
*  246 ** 0.81458E+02 * 0.26348E+02 * 0.56875E+02 ** 0.24816E+02 * 0.60112E+01 * 0.13694E+02 ** 0.23007E+00 *
*  247 ** 0.10051E+03 * 0.32091E+02 * 0.52868E+02 ** 0.24065E+02 * 0.85549E+01 * 0.14590E+02 ** 0.36709E+00 *
*  248 ** 0.83579E+02 * 0.42171E+02 * 0.45818E+02 ** 0.20982E+02 * 0.94704E+01 * 0.11786E+02 ** 0.37624E+00 *
*  249 ** 0.91766E+02 * 0.68106E+02 * 0.39118E+02 ** 0.21475E+02 * 0.15122E+02 * 0.95743E+01 ** 0.48406E+00 *
*  250 ** 0.26929E+02 * 0.10425E+02 * 0.65566E+02 ** 0.15796E+02 * 0.18929E+01 * 0.90717E+01 ** 0.13701E+00 *
*  251 ** 0.85978E+02 * 0.27375E+02 * 0.59906E+02 ** 0.27075E+02 * 0.65674E+01 * 0.15970E+02 ** [illegible] *
*  252 ** 0.10346E+03 * 0.35516E+02 * 0.56272E+02 ** 0.11534E+02 * 0.55474E+01 * 0.15939E+02 ** 0.35640E+00 *
*  253 ** 0.85492E+02 * 0.44442E+02 * 0.52936E+02 ** 0.22018E+02 * 0.10291E+02 * 0.12933E+02 ** 0.38361E+00 *
*  254 ** 0.95686E+02 * 0.68312E+02 * 0.38461E+02 ** 0.22685E+02 * 0.15429E+02 * 0.96751E+01 ** 0.50418E+00 *
*  255 ** 0.32883E+02 * 0.17747E+02 * 0.71638E+02 ** 0.17257E+02 * 0.22433E+01 * 0.10304E+02 ** 0.16253E+00 *
*  256 ** 0.85938E+02 * 0.25401E+02 * 0.60912E+02 ** 0.28531E+02 * 0.61215E+01 * 0.15465E+02 ** 0.25211E+00 *
*  257 ** 0.96224E+02 * 0.35938E+02 * 0.58498E+02 ** 0.25631E+02 * 0.92706E+01 * 0.15759E+02 ** 0.33556E+00 *
*  258 ** 0.88807E+02 * 0.47661E+02 * 0.54541E+02 ** 0.23407E+02 * 0.11426E+02 * 0.13634E+02 ** 0.39425E+00 *
```

THE UNIVERSITY OF ALBERTA

```
*  259 ** 0.95021E+02 * 0.69280E+02 * 0.39666E+02 ** 0.22750E+02 * 0.15782E+02 * 0.55497E+01 ** 0.48315E+00 *
*  260 ** 0.48771E+02 * 0.21509E+02 * 0.71624E+02 ** 0.18743E+02 * 0.34330E+01 * 0.12531E+02 ** 0.20828E+00 *
*  261 ** 0.93849E+02 * 0.27762E+02 * 0.63173E+02 ** 0.31526E+02 * 0.71942E+01 * 0.17195E+02 ** 0.29685E+00 *
*  262 ** 0.85048E+02 * 0.14524E+02 * 0.82530E+02 ** 0.24473E+02 * 0.81304E+01 * 0.15492E+02 ** 0.30633E+00 *
*  263 ** 0.87872E+02 * 0.47620E+02 * 0.56230E+02 ** 0.23512E+02 * 0.11435E+02 * 0.14562E+02 ** 0.36815E+00 *
*  264 ** 0.96027E+02 * 0.69921E+02 * 0.39137E+02 ** 0.23033E+02 * 0.15992E+02 * 0.58476E+01 ** 0.44542E+00 *
*  265 ** 0.54882E+02 * 0.23202E+02 * 0.72134E+02 ** 0.19597E+02 * 0.40351E+01 * 0.13553E+02 ** 0.23208E+00 *
*  266 ** 0.89176E+02 * 0.26872E+02 * 0.66904E+02 ** 0.30735E+02 * 0.67472E+01 * 0.10220E+02 ** 0.32128E+00 *
*  267 ** 0.89800E+02 * 0.37216E+02 * 0.65576E+02 ** 0.26590E+02 * 0.93359E+01 * 0.17037E+02 ** 0.34025E+00 *
*  268 ** 0.87747E+02 * 0.51221E+02 * 0.59660E+02 ** 0.27391E+02 * 0.12417E+02 * 0.14952E+02 ** 0.39059E+00 *
*  269 ** 0.96920E+02 * 0.70590E+02 * 0.39081E+02 ** 0.23530E+02 * 0.16327E+02 * 0.10117E+02 ** 0.49605E+00 *
*  270 ** 0.58196E+02 * 0.25209E+02 * 0.75099E+02 ** 0.20026E+02 * 0.45992E+01 * 0.14655E+02 ** 0.25081E+00 *
*  271 ** 0.87648E+02 * 0.27244E+02 * 0.70449E+02 ** 0.30647E+02 * 0.68372E+01 * 0.18581E+02 ** 0.32333E+00 *
*  272 ** 0.80900E+02 * 0.39648E+02 * 0.67918E+02 ** 0.26076E+02 * 0.99307E+01 * 0.17555E+02 ** 0.34369E+00 *
*  273 ** 0.96886E+02 * 0.65592E+02 * 0.58868E+02 ** 0.27092E+02 * 0.14723E+02 * 0.15856E+02 ** 0.42433E+00 *
*  274 ** 0.49786E+02 * 0.70994E+02 * 0.39519E+02 ** 0.24468E+02 * 0.16613E+02 * 0.10216E+02 ** 0.45773E+00 *
*  275 ** 0.60968E+02 * 0.27127E+02 * 0.77106E+02 ** 0.20185E+02 * 0.51496E+01 * 0.15490E+02 ** 0.27468E+00 *
*  276 ** 0.71161E+02 * 0.27194E+02 * 0.73850E+02 ** 0.23785E+02 * 0.58060E+01 * 0.16617E+02 ** 0.27478E+00 *
*  277 ** 0.82190E+02 * 0.37951E+02 * 0.70748E+02 ** 0.23689E+02 * 0.89837E+01 * 0.17186E+02 ** 0.31553E+00 *
*  278 ** 0.96725E+02 * 0.56604E+02 * 0.60558E+02 ** 0.27240E+02 * 0.14808E+02 * 0.16375E+02 ** 0.42584E+00 *
*  279 ** 0.98330E+02 * 0.70948E+02 * 0.39871E+02 ** 0.21994E+02 * 0.16518E+02 * 0.10233E+02 ** 0.47575E+00 *
*  280 ** 0.65709E+02 * 0.29406E+02 * 0.76556E+02 ** 0.20568E+02 * 0.58756E+01 * 0.16158E+02 ** 0.28367E+00 *
*  281 ** 0.90571E+02 * 0.33457E+02 * 0.75713E+02 ** 0.29986E+02 * 0.87027E+01 * 0.20618E+02 ** 0.35194E+00 *
*  282 ** 0.52004E+02 * 0.43194E+02 * 0.71813E+02 ** 0.27449E+02 * 0.11214E+02 * 0.19088E+02 ** 0.36578E+00 *
*  283 ** 0.96192E+02 * 0.59814E+02 * 0.60726E+02 ** 0.26948E+02 * 0.15339E+02 * 0.16340E+02 ** 0.41787E+00 *
*  284 ** 0.99167E+02 * 0.71197E+02 * 0.40722E+02 ** 0.24530E+02 * 0.16799E+02 * 0.10526E+02 ** 0.46441E+00 *
*  285 ** 0.72545E+02 * 0.33232E+02 * 0.78696E+02 ** 0.72157E+02 * 0.72431E+01 * 0.17840E+02 ** 0.31475E+00 *
*      **             *             *             **             *             *             **             *
**********************************************************************************************************
00:58149   T=47.132   PC=0
```